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SURFICIAL GEOLOGY OF THE BANFF AREA, ALBERTA

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY

by

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UNIVERSITY OF ALBERTA
FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Surficial Geology of the Banff Area, Alberta", submitted by Nathaniel Westlund Rutter, B.Sc., M.Sc., in partial fulfillment of the requirements for the degree of Doctor of Philosophy.



Mt. Rundle, Banff National Park, Alberta

(from an original oil painting by Lorne Roed)

ABSTRACT

The study was undertaken to map the surficial deposits in the Banff area and to determine the Quaternary stratigraphy and geological history. The study area comprises a part of the Bow River valley and certain tributary valleys within the Rocky Mountains. Till sheets are rarely in stratigraphic succession and cannot be differentiated on lithological characteristics; therefore reliance was placed on geomorphic criteria and the relationships between tills and other glacial deposits in deciphering the stratigraphy. Laboratory work was conducted mainly to describe the tills, to determine their provenance, and to test methods of correlation. Investigations performed were grain size analyses, roundness of pebbles, pebble composition counts, heavy mineral identification, clay mineralogy, carbonate content and dolomite-calcite percentages. The laboratory work indicates that all the tills in the Banff area are similar in composition and vary only as the underlying bedrock varies; and that the source of the ice was probably always in the area of the Continental Divide.

Four major ice advances are recorded. The Pre-Bow Valley advance, the earliest recorded in the Banff area, is indicated by outwash underlying the oldest till recognized. This advance is tentatively correlated with the Bull Lake Glaciation of the United States Rockies. The oldest till recognized was deposited during the Bow Valley advance, which extended into the Foothills. Ice-contact fluvial deposits, believed to have been originally kame moraines, indicate at least two times of glacier equilibrium during deglaciation. The Bow Valley advance is inferred to be equivalent in age to the early stade of the Pinedale Glaciation. The Bow Valley re-advance took place from about Banff townsite and probably extended into the Foothills. This event is recorded by erosional surfaces and discontinuous patches of till over outwash. It is correlated with the middle stade of the Pinedale. The next advance, the Eisenhower Junction, extended about as far as Eisenhower Junction. Evidence for it includes well preserved ground and lateral moraines, erosional surfaces, fresh cirques,

and a terminal moraine. A minor re-advance followed, as shown by till over ice-contact fluvial deposits laid down during the deglaciation of the Eisenhower Junction advance. A radiocarbon date of 9330 ± 170 years B.P. from a nearby area indicates the age of the Eisenhower Junction advance and re-advance to be about equivalent to the late stage of the Pinedale Glaciation.

The Altithermal interval is indicated by wind-blown material containing a volcanic ash layer tentatively correlated with the Mt. Mazama ash. Two levels of cirque development probably followed the Altithermal. This succession, along with cirques at lower elevations which developed earlier, are present in several valleys in the Banff area. End moraines near modern glaciers, or in recently vacated cirques, are located near Horseshoe Glacier, and in Larch Valley; a questionable end moraine occurs near the southwest end of Moraine Lake. These cirques and end moraines correlate with the Neoglaciation. A late nineteenth century advance evidenced by the ice-cored end moraine of the Wenkchemna Glacier is equated with the Gannett Peak stage of the Neoglaciation.

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CHAPTER 1 - INTRODUCTION

General Statement

The diverse and perplexing Quaternary deposits and erosional features in the Banff area have intrigued numerous students of natural history, but only a few have made statements regarding the Quaternary history of the area.

The purpose of the present study was to investigate in detail surficial deposits of the Banff area in order to arrive at a better approximation of the geologic history of the region. Not all of the problems have been solved. Nevertheless, a general scheme of major events occurring during the latter part of the Quaternary Period is presented which explains most of the erosional and depositional features of the surficial geology.

Location and Area

Since it was necessary to work at the site of an existing glacier and in a major outlet valley in order to get the most complete picture of the glacial activity during the Quaternary Period, the area selected for the study encompasses the Wenckhemna Glacier, the Valley of the Ten Peaks, and the Bow River valley from the junction of the Valley of the Ten Peaks as far as the Kananaskis River (Figure 1; Map 1,2,3). The dimensions of the area are roughly 65 miles by 1.5 miles, or approximately 100 square miles, and includes portions of the National Topographic System maps 82 0/3, 0/4, 0/5, 0/6, N/1, and N/8, within north latitudes $51^{\circ}30'$ and $51^{\circ}00'$, and west longitudes $116^{\circ}15'$ and $115^{\circ}00'$.

Field Work

The entire 1963 field season, the major part of the 1964 season, and two weeks in 1965, a total of seven and a half months, were devoted to field work in the Bow River valley. Mapping was performed by interpretation of air photographs (scale: 1:40,000). The different deposits were then checked in the field, and the



Figure 1. Index map of the Banff area.

the combined information was transferred to National Topographic System maps on a scale of 1:50,000. It soon became apparent that the only information that could be obtained from air photographs with any assurance was the position of contacts between post-glacial deposits, such as alluvial fans, floodplain deposits, and ice-cored moraines. Thus, airphoto interpretation was of little value in considering the majority of the deposits. Field work was hampered by a thick vegetation. Limited exposures are present almost exclusively along major highways and larger rivers and creeks. The significance of mapped contacts between deposits is often questionable because of the limited exposures and the gradational nature of the surficial deposits, often a continuum between two end members.

Vertical lithological sequences, fossils, and Pleistocene age dating materials are scarce, making it difficult to work out a basic stratigraphy and geologic history. Therefore, great reliance was placed on physiography in establishing these ends. Such factors as relative positions of end and lateral moraines, amount, kind, and elevation of glacial scouring, relative size of alluvial fans, maturity and drainage changes of rivers and creeks, and positions of cirques were of prime importance.

Laboratory Work

Laboratory work was conducted mainly on till, although loess was also analysed. The principal objectives of the laboratory work were to describe accurately the surficial deposits, to gather information that might be used in correlating tills, to decipher the provenance of the tills, and to investigate factors important in determining the genesis of till. The following investigations were performed: grain size analyses, roundness of pebbles, pebble counts, heavy mineral identification, clay mineralogy, carbonate content, and dolomite-calcite percentages.

General Statement

No detailed study of the Quaternary geology had previously been undertaken for the Banff area. No study of a comparable nature has been reported in the southeastern Canadian Rocky Mountains.

Reports on this area or vicinity that consider some aspect of the Quaternary geology can be grouped under three categories: General Geological Reports (and a few early surficial geological reports), Glacial Geological Reports, and Glaciological Reports.

General Geological Reports

The first person to make geological observations on the Bow River valley area of the Rocky Mountains was probably James Hector, a scientist on the Palliser Expedition. From 1858 to 1860, Hector (1861) studied the geology between Lake Superior and the Pacific Ocean between the 48th and 54th parallels. He mentioned the presence of glacial deposits throughout the Bow River country, attributing them to ice rafting.

Subsequent work in the area was more detailed. The trend shown by the literature seems to be to move from a general approach to the geology in early work to a restricted approach in later work, with Quaternary geology being almost entirely excluded. G.M. Dawson, a geologist for the Geological Survey of Canada, and his assistant, R.G. McConnell, did the first detailed geological work in western Canada. Dawson published between 1875 and 1895 (Dawson 1875, 1883, 1885, 1886, 1890a, 1890b; Dawson and McConnell 1895), a series of papers on all aspects of the geology in the western part of the Great Plains and the Rocky Mountains. In most papers he described the surficial deposits, and in 1886 commented on the drainage changes of the Bow River within the mountains. Later Dawson (1890a) proposed a correlative scheme between glaciation in the Canadian

Cordillera and glaciation in the western Great Plains. Other contributors of that era included McConnell (1887) and Ogilvie (1904), who proposed histories of drainage changes of the Bow River within the mountains. Wilcox (1899) worked out a sequence of different tills near Banff townsite and Coleman (1910) devoted an entire report to the drift and to the relationship between the Cordilleran and Keewatin ice sheets.

Geological reports published after 1910 contain little information on the Quaternary geology of the area under consideration. The more important papers include Warren (1927), Mackay (1940), Heusser (1956), and Belyea (1960). One or more of these reports describe the glacial scenery, glacial drift, changes in drainage of the Bow, Cascade, and Spray Rivers and note the height at which glacial erratics have been found. Other papers that deal with certain aspects of the Quaternary geology in the study area or in surrounding areas include publications of Allan (1914, 1917), Daly (1915), Steward (1919), Rutherford (1927), Beach (1943), and Bostock (1948).

Glacial Geological Reports

No reports in this category deal specifically with the study area, but some describe areas in the vicinity and should be included in the record, although few have a direct bearing on the conclusions drawn by the writer.

Stratigraphic studies are confined to areas outside of the Rocky Mountains in the Foothills that were affected both by continental and Cordilleran ice. These include a report by Nichols (1931), who studied terminal moraines of the Pleistocene ice sheets in the Jumpingpound-Wildcat Hills area; Horberg (1954), who published a report on the Waterton region; and Tharin (1960), who worked out the glacial geology of the Calgary area. Stalker (1963) described sections east of Crow's Nest Pass, some of which include both continental and Cordilleran glacial sediments.

Glacial geomorphology and its stratigraphic implications in the Sunwapta Pass region were presented by Jennings (1951). Geomorphological reports on glacial deposits in the Morley Flats area and the upper Red Deer River valley are by Nelson (1963) and McPherson (1963), respectively.

Glaciological Reports

Glaciological observations have been made more or less systematically on glaciers in the Banff area and vicinity (Figure 2, Table I). The Wenkchemna Glacier is the only one in the area of investigation that has been studied. Most of the investigations are of minor importance to the present study because they are limited to the active ice. An exception to this is a report by Sherzer (1907), who worked out the recent glacial history of the Banff area by utilizing information derived from recent moraines of the Asulkan, Illecillewaet, Victoria, Yoho, and Wenkchemna Glaciers.

In 1948 Meek reviewed the work that has been carried out on glaciers in the Canadian Cordillera. Heusser (1956) evaluated the available data on glaciers in the Canadian Rocky Mountains and combined it with information from other disciplines, particularly botany, to reconstruct post-glacial environment. McCauley (1958) presented a summary of available data on most of the glaciers in this area as part of a larger work covering statistics of all glaciers of the northern hemisphere.

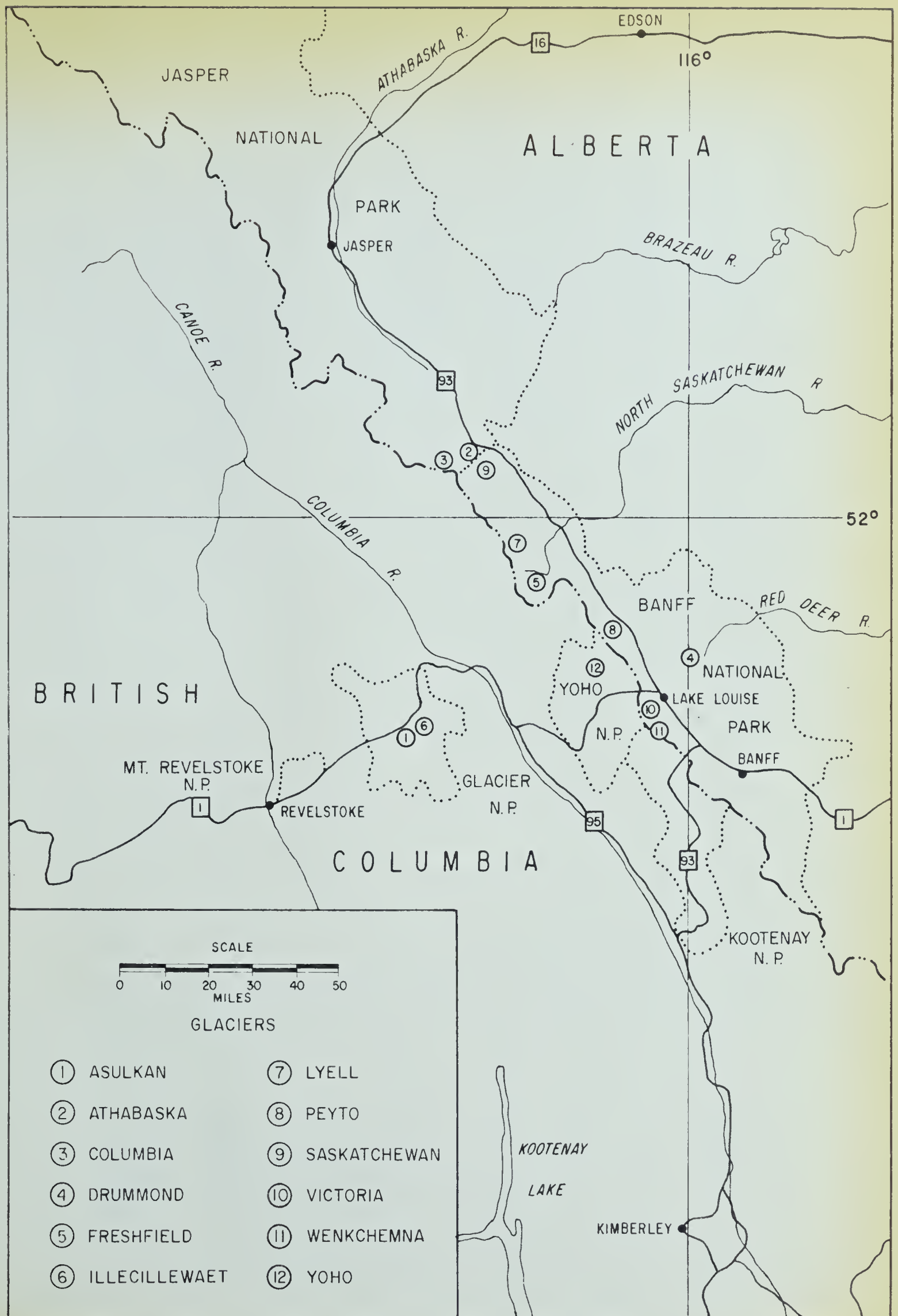


Figure 2. Locations of existing glaciers in the Banff area and vicinity.

TABLE I

Investigations of Existing Glaciers- Banff Area and Vicinity

Glacier	Investigations
1 Asulkan	Vaux (1909, 1913), Vaux, Jr. and Vaux (1907, 1911), Vaux, Jr. (1910), Wheeler (1907, 1908, 1911, 1913, 1915, 1917, 1918, 1920a, 1920b, 1932, 1933), Sherzer (1907).
2 Athabaska	McFarland (1946), Field (1949), D.W.P.B.* (1948, 1949, 1951, 1954), Peterson (1962).
3 Columbia	Field (1949).
4 Drummond	Gardner and others (1964).
5 Freshfield	Palmer (1924), Thorington (1927, 1931, 1938, 1945), McCoubrey (1937).
6 Illecillewaet	Vaux (1909, 1913), Vaux, Jr. and Vaux (1907, 1911), Vaux Jr. (1910), Wheeler (1907, 1908, 1911, 1913, 1915, 1917, 1918, 1920a, 1920b, 1932, 1933), Sherzer (1907).
7 Lyell	Thorington (1927, 1931, 1938, 1945), McCoubrey (1937).
8 Peyto	McCoubrey (1937), McFarland (1946), D.W.P.B. (1948, 1949, 1951, 1954).
9 Saskatchewan	Thorington (1927, 1931, 1938, 1947), McCoubrey (1937), McFarland (1946), Field (1949), D.W.P.B. (1948, 1949, 1951, 1954), Meier (1960).
10 Victoria	Vaux (1909, 1913), Vaux, Jr. and Vaux (1907, 1911), Vaux, Jr. (1910), Wheeler (1907, 1908, 1911, 1913, 1917, 1918, 1920a, 1920b, 1932, 1933), Sherzer (1907), McFarland (1946), D.W.P.B. (1948, 1949, 1951, 1954).
11 Wenkchemna	Vaux (1909, 1913), Vaux, Jr. and Vaux (1907, 1911), Vaux, Jr. (1910), Wheeler (1907, 1908, 1911, 1913, 1917, 1918, 1920a, 1920b, 1932, 1933), Sherzer (1907).
12 Yoho	Vaux (1909, 1913), Vaux, Jr. and Vaux (1907), Wheeler (1907, 1908, 1909, 1910, 1911, 1913, 1917, 1918, 1920a, 1920b, 1932, 1933), Sherzer (1907), McFarland (1946), D.W.P.B. (1948, 1949, 1951, 1954).

* Dominion Water and Power Bureau.

CHAPTER 2 - PHYSIOGRAPHY

General Statement

The area under discussion is situated in the eastern watershed of the Canadian Rocky Mountains section of the North American Cordillera physiographic province. The topography is controlled principally by differential erosion and structure of the bedrock modified by glacial erosion and deposition. The regional strike of the mountain ranges, and also the bedrock structure, is about north 30° west. The mountain ranges are separated by rivers and creeks that form a trellis drainage pattern in which the principal streams are subsequent for all or most of their courses. The mountains are rugged, displaying a "textbook" example of glacial alpine morphology with abundant cols, arêtes, horns, cirques, hanging valleys, U-shaped valleys, and polished surfaces. Intense post-glacial subaerial erosion is rapidly modifying the existing landforms.

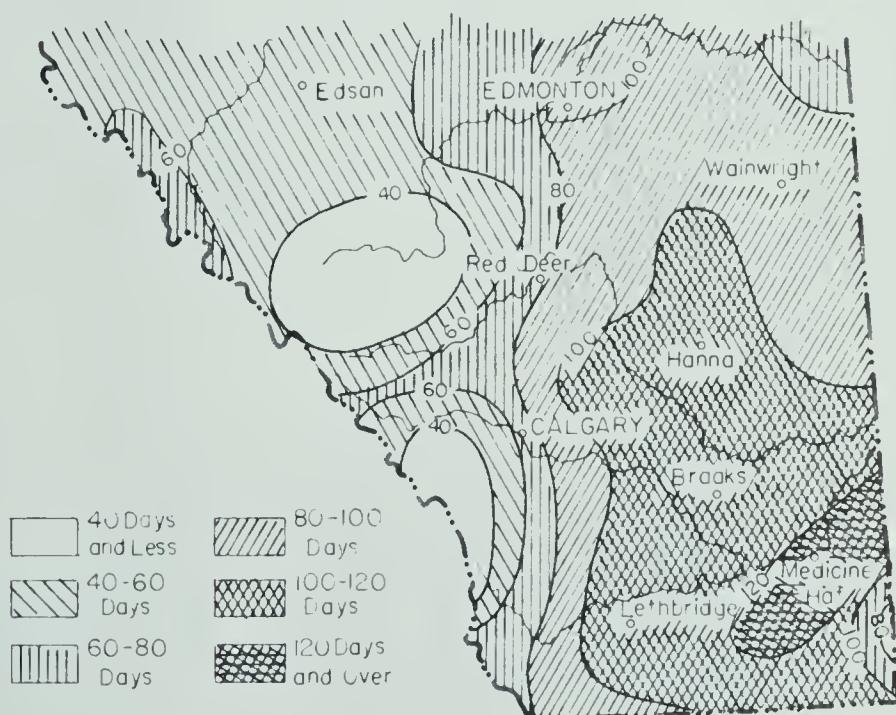
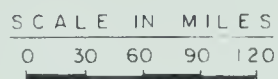
Climate

The climate of the Banff area is essentially continental. From September to June, polar marine air masses move inland from the North Pacific across the mountains, being cooled in the process (Heusser 1956). By the time the masses reach the Banff area, they resemble continental air, but are not as cold or dry. During the summer, however, Pacific air moving east mixes with the dry air above and becomes indistinguishable from dry continental air by the time it crosses the Continental Divide. Polar continental air masses developed in the arctic sometimes affect the Banff area also, principally in the winter. The net effect of these air masses is a fairly evenly distributed monthly precipitation and an extreme seasonal variation of temperature.

Climatic data for the study area and southern Alberta are given in Table II and Figure 3. Since the late 1930's, the average temperature has fallen 2°F in the



NORMAL ANNUAL PRECIPITATION IN INCHES



MEAN FROST FREE PERIOD

(AFTER ALBERTA BUREAU OF STATISTICS, 1964)

Figure 3. Normal annual precipitation and mean frost-free periods for southern Alberta.

TABLE II

Meteorological Data from Weather Stations in the Banff Area

	Lake Louise elev. 5032'	Banff elev. 4583'	Anthracite elev. 4550'	Exshaw elev. 4260'
Precipitation				
Mean Total yearly (in inches)	30.8	18.7	18.2	20.5
Rain (in inches)	11.3	10.9	11.6	12.5
Snow (in inches)	19.5	7.8	6.6	7.8
Days with at least 0.01 inches precipitation	141	123	85	91
Days with at least 0.1 inches snow	79	58	31	37
Number of years observed	30	29	30	15
Temperature				
Yearly mean (°F)	32	36	37	39
Yearly daily maximum (°F)	46	47	49	49
Yearly daily minimum (°F)	18	25	25	29
Maximum month (mean) (°F)	55, July	58, July	58, July	61, July
Minimum month (mean) (°F)	6, Jan.	13, Jan.	13, Jan.	19, Jan., Feb.
Number of years observed	30	29	30	15
Wind				
Yearly mean speed (mph)	--	6	--	--
Maximum percent frequency	37 W	38 SW	--	55 SW
Minimum percent frequency	1 NE	3 N, SE, S	--	0 S
Number of years observed	6	24	--	8

Banff area, whereas the precipitation has increased by more than 4 inches, with over 75% of this occurring as snow (Heusser 1956, p. 268).

Vegetation

The Banff area can be separated into two phytogeographic regions: the Alpine Region and the Subalpine Forest (Moss 1955; Figure 4).

Alpine Region

The lower limit of the Alpine Region varies between 8,000 and 6,500 feet, with 7,200 feet being the average (Moss 1955). Three zones can be distinguished in this region: forest line to tree line, tree line to scrub limit, and above scrub limit. The lower band above the forest line is characterized by groves and isolated individuals of Engelmann spruce (Picea engelmanni), alpine fir (Abies lasiocarpa), alpine larch (Larix lyalli), and white-bark pine (Pinus albicaulis), often stunted and distorted. In the next zone, these species persist, but are even more stunted and distorted. Alpine meadows, prevalent in this area, consist of a variety of grasses, broad leaf plants and herbs. Above the scrub limit, the vegetation consists mainly of small plants, many of which have circumpolar distribution.

Subalpine Forest

The Subalpine Forest, consisting mainly of conifers, is enclosed in the Banff area by elevations between approximately 7,200 and 4,200 feet (Moss 1955). In the upper reaches, Engelmann spruce and alpine fir, which represent the climax forest, are the principal tree varieties present. Occasionally, stands of white-bark pine, limber pine (Pinus flexilis), alpine larch, and lodgepole pine (Pinus contorta) are found. In the middle and lower elevations, Engelmann spruce and alpine fir are well developed, but less abundant. Here, white spruce (Picea glauca) partially replaces these varieties. White spruce is generally limited to elevations below 5,000 feet, and Engelmann above 6,000 feet. Hybrids of these two varieties exist. Lodge-

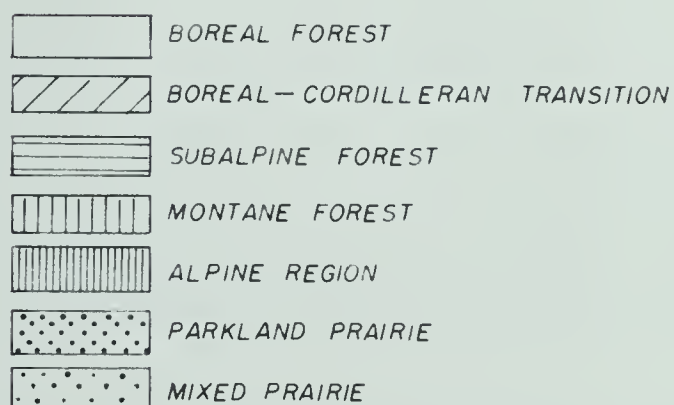
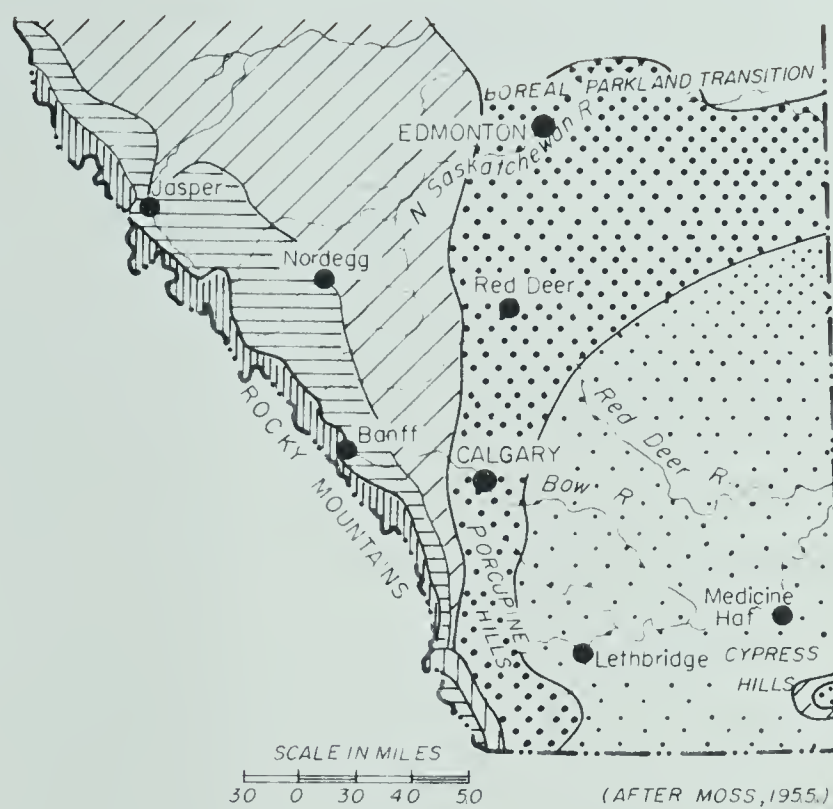


Figure 4. Main phytogeographic regions of southern Alberta.

pole pine and trembling aspen (Populus tremuloides) are extremely common, but temporary, being replaced by the spruce-fir climax forest. The quantity of aspen and lodgepole pine is controlled by the extent and intensity of fire, aspen usually appearing when fire has been less intense. Black spruce (Picea mariana) commonly grows in and near marshes, and Douglas fir (Pseudotsuga menziesii) is found on the uplands on protected slopes.

Soils

No soil surveys have been carried out in the area under investigation. However, a field trip was conducted by members of the Canadian Society of Soil Science in 1963, on which they published a pamphlet describing certain soil horizons in the Bow River valley, Banff area (Alberta Soil Survey 1963). Additional information was provided by Mr. W.E. Bowser, Canada Department of Agriculture.

In the better drained portions of the floor of the Bow River valley, soils of the podzolic order are the most common. Between Seebe and Exshaw, the predominant soils are gray wooded; from Exshaw to about 10 miles northwest of Banff townsite, a mixture of brown wooded and bissequa gray wooded are present; and from there to at least Moraine creek minimal podzols occur. In the poorly drained areas along this route, black meadow soils are predominant. At the higher elevations in better drained areas, orthic podzols are present, while alpine meadow soils appear in poorly drained areas.

There are, in addition, areas of peat, lithosols, and immature soils.

Physiographic Units

The area under investigation can be conveniently subdivided into three physiographic units: the Alpine Region, the Major Valleys, and the Kame Moraine Region.

Alpine Region

General Statement

The Alpine Region consists essentially of the upper reaches of the mountains bordering the Bow River valley and certain tributaries (Figure 5). The lower boundary roughly corresponds to the upper limits of two prominent glacial advances, one terminating at Eisenhower Junction and the other beyond the area of investigation, being at an elevation of approximately 7,000 feet in the northwestern part of the study area near Moraine Lake, and decreasing to about 4,500 feet in the vicinity of the town of Exshaw in the southeastern part.

The entire study area is located within parts of the Main Ranges and Front Ranges of the Canadian Rocky Mountains, with the exception of a small part of the Foothills at the eastern limit of the area. The highest mountains are between about 8,000 and 10,000 feet, the highest being Mt. Temple at 11,626 feet. The local relief varies between approximately 4,000 and 6,000 feet in respect to the Bow River valley floor. The rock consists mainly of Precambrian and Paleozoic strata folded and thrust to the northeast.

The basic morphology of the terrain is controlled by the bedrock geology modified principally by glacial action. From Eisenhower Junction northwestward (the Main Ranges), the beds dip only slightly, forming a broad syncline on the northeast side and parallel to the Bow River valley and probably a similar syncline on the other side. Differential erosion of varying lithologies has formed bench-and-slope topography, which is rugged but uniform. The outstanding example is Mount Eisenhower (Plate IA). On the southwest side of the valley, bench-and-slope topography is not as pronounced, because of lesser variations in lithology and a greater degree of alpine glacier sculpturing (Plate IB). In the upper reaches of many of the mountains, such as Mt. Eisenhower, castellated forms consisting of delicate pillars are present. The major valleys are crudely symmetrical in this region.

Southeast of Eisenhower Junction (the Front Ranges), the strata are more

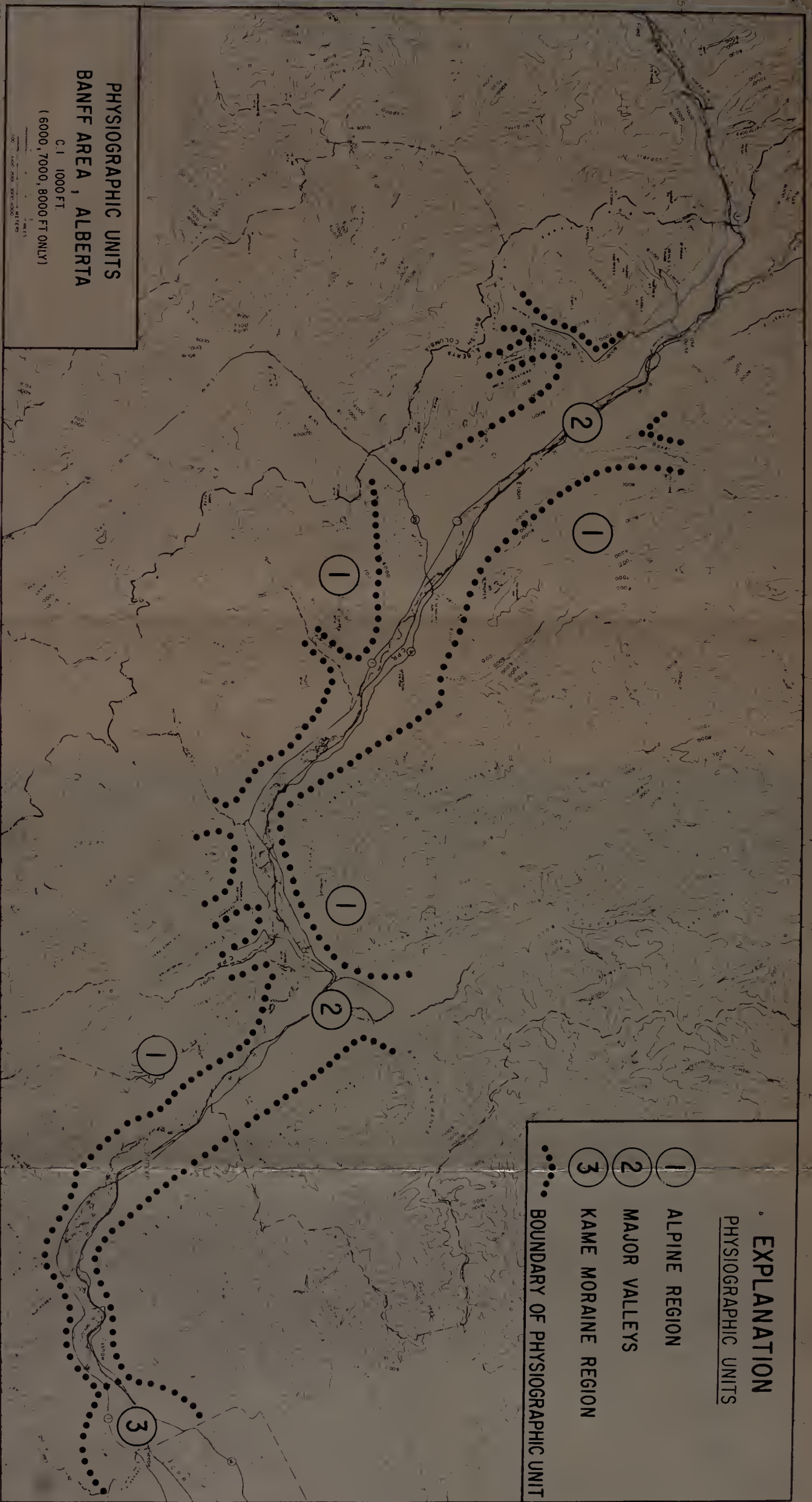


FIGURE 5

steeply dipping, generally toward the southwest. Increase in dip results in more exposure of narrow bands of varying lithologies, causing rough slopes, serrated ridges, jagged peaks, and a decrease in elevation. In the Front Ranges, it is commonly observed that the northeast wall of a valley is a dip slope (Frontispiece), whereas the opposite wall is a back slope exposing a variety of rocks, including relatively softer units. These differences in structure and lithology result in asymmetrical valleys.

Present day erosion occurs at a prodigious rate. Stream action and mass-wasting by avalanching are most important. Streams whose valleys were left hanging during deglaciation are rapidly eroding to a new local base level, forming narrow, steep-sided canyons. Avalanches are extremely active in spring. Standing near the Wenkchemna Glacier in the middle of June 1964, the writer could spot and hear avalanches at two or three minute intervals all day. The summits of the mountains offer the only indication of former erosion surfaces in the area under investigation. The Rocky Mountains are strikingly similar in height. In the Sikanni Chief River country (northwest of Fort St. John, B.C.), remnants of an old surface truncate many of the summits (Bostock 1948, page 9). These surfaces are absent in the Banff area, possibly because of greater glacial activity.

In the northwest part of the area, a few cirque glaciers are present. The major one is the Wenkchemna, which is a reconstructed glacier of the horseshoe type, (Charlesworth 1957, p. 88,91) located above Moraine Lake between 6,400 and 8,000 feet. It is nestled on the southern side of a prominent cirque with steep walls; it covers about 2 square miles and consists mainly of ice-cored moraine, with about 2 to 4 feet of ablation debris. The surface is hummocky because of differential ablation mainly by superglacial and englacial stream erosion, which often exposes clear ice below the ablation moraine (Plate IIA). A well developed equilibrium moraine, with higher relief than the rest of the stagnant ice follows the periphery of the glacier. The height of the firn line, which is difficult to determine, is app-

roximately 7,900 feet.

Above Consolation Lakes and Boom Lake, a few miles southeast of the Wenkchemna Glacier, are cirque glaciers consisting mainly of stagnant ice. The former has an area of less than one square mile, a northern exposure, and a firn line at roughly 8,000 feet, while the latter has an area of about 2 square miles, a southeastern exposure, and a firn line at approximately 8,300 feet.

Perennial patches of snow and ice as well as small cirque glaciers appear in other spots in the northwest part of the area, such as above Taylor Lake and Twin Lakes.

Glacial Erosional Features

Cirque development is widespread. The cirques do not support glaciers at present, except for those glaciers mentioned above. Former snowlines estimated from cirque floors vary between 6,200 and 8,250 feet, with the majority from 6,750 to 7,300 feet. This variation is caused by differences in exposure, topography, precipitation and temperature, latitude, structure and lithology of bedrock, and paleoclimates, as evidenced by succession of two or three cirques in the same valley in certain instances (Plate III).

Cirques increase in total number and are better preserved toward the northwestern part of the area, mainly because of more recent glacial activity in the area of the Continental Divide and favorable bedrock structure. Also, more cirques have developed on the northerly exposed side of the mountains. Distribution of well developed cirque successions is shown in Figure 6, with examples of past climatic snowlines in Table III. There are never more than three cirques in a valley. It was impossible to correlate cirques in different valleys outside of local areas, making it difficult to prove or disprove the hypothesis that there were more than three periods of cirque development. One would expect, however, that if this were the case, four or more successive cirques would appear in at least one valley.

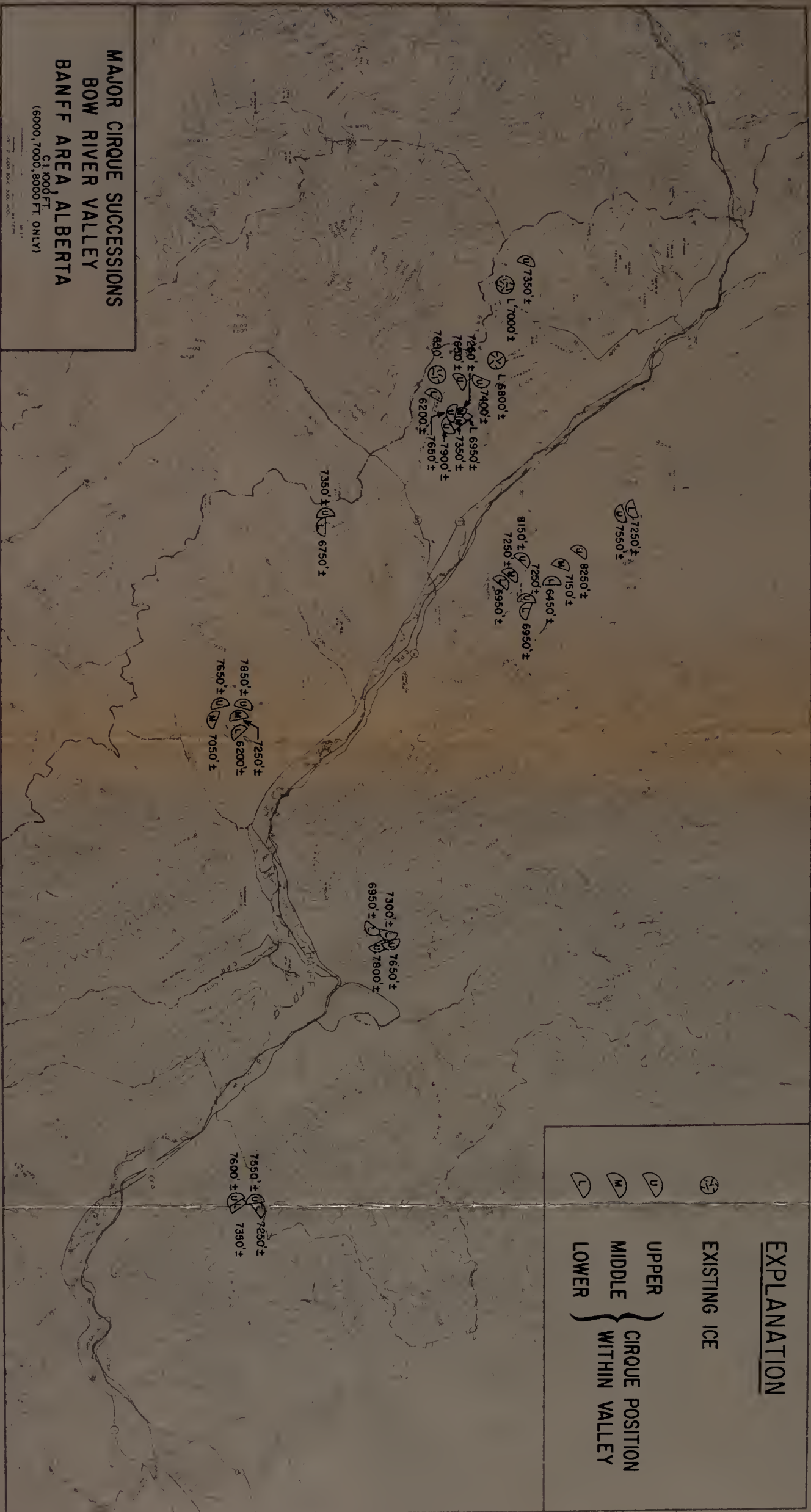


FIGURE 6

TABLE III

Estimates on past climatic snowlines derived from cirque floors.

Location of cirques	Cirques within a single valley		
	Lowest elevation (ft)	Middle elevation (ft)	Highest elevation (ft)
Southeastern exposure Mt. Eisenhower	6,950+ _—	7,250+ _—	8,150+ _—
Southeastern-eastern exposure, Mt. Eisenhower	6,450+ _—	7,150+ _—	8,250+ _—
Northeastern exposure Mt. Bell	6,950+ _—	7,250+ _—	7,650+ _—
Eastern exposure Mt. Brett	6,200+ _—	7,250+ _—	7,850+ _—

The times of development of the successive cirques are believed by the writer to be no earlier than late Wisconsin age for the following reasons:

1. Cirques are generally believed to form and enlarge at a rapid rate by glacial erosion (Flint 1947, p. 100). This would occur in areas of maximum nivation, which would be at about the orographic snowline if the snowline is relatively stable.

2. During interglacial times, erosion would obliterate cirques quickly, as evidenced by the rapid rate of erosion in the Banff area today.

One would expect the preservation of a cirque to be more likely as a pausing snowline ascends. This rise would indicate a less severe climate and development of successively smaller glaciers, perhaps confined to each cirque developed. If, however, a glacier overflowed its cirque, it probably would destroy the cirque below. This overflowing is probably rare for the simple reason that the climate is becoming less severe. If, on the other hand, the snowline was descending, which indicates a more severe climate, the higher cirques would very likely be destroyed

because of the progressively greater build-up of snow and ice from below. This interpretation corresponds to a multitude of similar interpretations for cirques in tiers or tandem cirques in the Carpathians, Alps, Sweden, and many other areas of the world.

Therefore, in the Banff area, the snowline was probably ascending when the cirques in succession were developed. However, the uppermost cirques on Mt. Eisenhower appear older than lower ones, as evidenced by alteration of the basic form, and truncation of the lip by the next lower cirque (Plate III). This reverse succession could result from protected glaciers occupying the lower cirques at a later time than the development of the last cirque, and thus keeping them "alive". The alternative is that glaciers present today or in the recent past could represent a relatively recent lowering of the climatic snowline and therefore represent a separate time of glacier development. The writer believes, however, that this probably is not true because of the sporadic positions of the existing glaciers, their poor development, and the protected nature of many of the lower cirques that support glaciers or have recently supported glaciers.

Cols, horns, and arêtes are numerous and well developed in the northwestern part of the area. U-shaped valleys in the Alpine Region are found also in the northwestern part, usually as short extensions of cirques into the upper flanks of a major valley. In most cases, the glaciers which they contained did not reach the major valley glacier during the last major advance, as shown by morphology and occasional end moraines. Good examples occur in the Twin Lakes-Copper mountain and Massive Mountain areas, where a number of cirque glaciers had extended and eroded at nearly right angles into a previously glaciated surface (Map 1). One located near Twin Lakes developed a trough 400 feet deep, over a mile and a half long and three quarters of a mile wide. How great a part stream erosion played in developing the valley prior to glaciation is impossible to say. Such development is stratigraphically important and also illustrates the great amount of er-

osion a relatively small glacier was able to cause during the last major advance.

Other examples of U-shaped valleys include those extending from Taylor, Rockbound, O'Brien, and Boom Lakes. These are all relatively small, with the first three displaying what might be end moraines. The forest cover prevented an absolute determination.

In certain places limestone and dolomite, which constitute a large percentage of the total bedrock, have well preserved striations and polishing where the surface has been protected by overburden. Exposed areas have lost these features because of weathering.

In the Alpine Region, indications of the upper limits of glacial advances or equilibrium phases are sometimes observed. These consist of breaks in slope caused by glacial scouring below, and, usually, side glacial stream activity above. Any material which might have formed the upper limit of lateral moraines has been eroded. In some instances, the breaks in slope may reflect differential erosion of varying lithologies rather than indicating the highest elevation of glacial ice at a certain time. Location and other data concerning these phenomena are presented in Table IV. The breaks in slope in the Alpine Region probably represent the same advance. The maximum elevation of all breaks varies between 7,300 and 8,000 feet.

Glacial Depositional Features

Hummocky moraine in the Alpine Region is found toward the end of the Boom Creek valley and near Tower Lake on the northeast side of Mt. Eisenhower (Map 1). In the Boom Creek area till was deposited in the base of a bowl-shaped depression, approximately 1 1/2 square miles in area. The hummocks are poorly developed and irregular with the irregularities probably partially controlled by bedrock. Near Tower Lake, there is less than one-half square mile of hummocky moraine.

Other glacial depositional features are of minor physiographic importance

TABLE IV

Data concerning indicators of the upper limits of glacial advances or equilibrium phases and approximate ice thicknesses found in the Alpine Region. The maximum and minimum elevations refer to the same break in slope, but in different locations.

Location	Length of break in slope (miles)	Maximum elevation (feet)	Minimum elevation (feet)	Reliability of data	Approximate ice thickness (feet)
North side of The Valley of the Ten Peaks	2	8,200	6,200	questionable	2,200
Circumscribing Panorama Ridge	4 1/2	8,000	7,100	fair	2,600 (Bow Valley) 1,600 (Consolation Valley)
East side of Baker Creek valley	1	7,600	7,400	good	2,000
East side of Baker Creek valley	3/4	7,300	7,100	fair	2,000

Same advance or equilibrium phase

in the Alpine Region. Thin coats of glacial deposits, often discontinuous, are found near the lower boundary of the Alpine Region on valley walls, in U-shaped valleys, and in cirques.

Non-glacial Features

Mass-wasting processes, the most important products of which are talus slopes and rock glaciers, are very active in the Alpine Region. Well developed talus slopes are common at the base of steep slopes. The presence of vegetation on the slope depends on the elevation and rate of development. Below timber-line, narrow (about 300 or 400 feet) swaths of grasses and other low lying plants, as well as forest debris, are common on the steeper slopes. This is a result of snow, ice, and rock debris avalanching downslope principally during the spring, ripping out most of the forest on its way and adding material at the base. Other varieties of landslide deposits are rare. However, scars of landslides are common. A good example is the large gap on the southwest side of Protection Mountain (Map 1).

Rock glaciers were not investigated by the writer but can be seen on air photographs of the Copper Mountain-Twin Lakes region between 7,000 and 8,000 feet at the bases of the back walls of certain northerly exposed cirques (Map 1). Lobate and tongue-shaped varieties, with width and length less than 1,400 feet, dominate. Whether they are active is not known, but steep slopes, available material, lack of vegetation, and a near glacial climate indicate that they may be.

Rock-talus-and soil-creep are active throughout the Alpine Region.

Periglacial phenomena such as felsenmeer and polygonal ground are present on almost all fairly level surfaces above timber-line. Most of the material is highly angular and coarse (greater than 25mm.). Polygonal ground believed to be active because of the freshness of the stones and lack of vegetation was observed near Stuart Knob, about 2 miles northwest of Mt. Eisenhower.

A number of outwash and alluvial terraces are present in the lower part of

the U-shaped portion of the Johnston Creek valley. The former occur near the valley sides, with prominent scarps, whereas the latter occur toward the creek or center of the valley, with scarps only a few feet high.

Lakes of glacial origin in the Alpine Region fall generally into two categories: rock basin and moraine dammed. Rock basin lakes, represented by tarns, includes Rockbound, Tower, O'Brien, Taylor and Twin Lakes, whereas Boom Lake is moraine dammed. Lakes of non-glacial origin are absent except for an artificial lake constructed for hydroelectric power above Canmore.

Major Valleys

General Statement

The upper boundary of this physiographic unit corresponds to the lower limit of the Alpine Region physiographic unit represented by the upper limits of two prominent glacial advances. The area includes the lower portion of the Bow River valley and the major tributaries that enter it (Figure 5). This region is principally one of aggradation of both glacial and non-glacial deposits.

Glacial Erosional Features

All of the large valleys in this area and small valleys in the northwestern part are outstanding examples of U-shaped valleys (Maps 1, 2, and 3).

Many of the better developed tributary U-shaped valleys of the Bow River valley are hanging valleys. Generally, the larger the tributary, the lower its position above the floor of the Bow River valley.

The difference in relief between the lip of the hanging valley and the base of the Bow River valley near the present Bow River floodplain gives an approximation of the amount of truncation in the main valley. Complications may render the approximation invalid if, for example, the valleys involved have surficial deposits of different depths. Data concerning the above are presented in Table V.

The most important indicators of the upper limit of glacier ice are found in

TABLE V

Hanging valley elevations of the Bow River valley tributaries at selected areas.

Location	Approximate elevation of hanging valley lip (feet)	Approximate elevation of the base of the Bow River valley next to the present Bow floodplain (feet)	Amount of truncation (feet)
The Valley of the Ten Peaks	5,700	4,950	750
Baker Creek valley	5,300	4,950	350
Sundance Creek valley	5,100	4,600	500

this physiographic unit. Most are breaks in slope, but a few are lateral moraines. On the northwest side of The Valley of the Ten Peaks is a well developed lateral moraine that corresponds to another on the west side of Panorama Ridge. However, as this moraine is followed around Panorama Ridge (with one three-quarter mile break) into the southwest side of the Bow River valley, there is a transition into a bedrock step, with the upper limit of the advance being indicated by a break in slope which can be followed to within 1 1/2 miles of Route 93 near Eisenhower Junction (Figure 7 , Section A-A'; Map 1).

In the lower end of Baker Creek valley, there is a good break in slope on the western side and two poorly defined breaks in the eastern side of the valley probably equivalent in age to those mentioned above. Below these breaks on either side of Baker Creek valley are two other breaks, poorly defined and discontinuous, at different elevations with respect to each other, probably representing different glacial advances. The break in slope on the eastern side can be correlated with three others; one poorly defined on the east side of Baker Creek valley, and two well defined on the northeast side of the Bow River valley near Eldon.

A break in slope southeast of Redearth Creek is fairly well defined, but cannot be equated to any other glacier limit.

Southeast of Banff townsite to near Canmore, breaks in slope are present in several areas, representing a glacial advance probably older than any of those mentioned previously in this section. These are well defined and located in three widely spaced areas on the southeastern side of the Bow River valley (Figure VII, Section B-B'; Map 3).

Table VI presents data concerning the above discussion.

Extending from the Tower of Babel into the Bow River valley is a prominent ridge about 2 miles long, at an elevation varying between 6,500 and 5,900 feet. It represents a trace of the medial moraine between the glaciers of The Valley of the Ten Peaks and Consolation Valley.

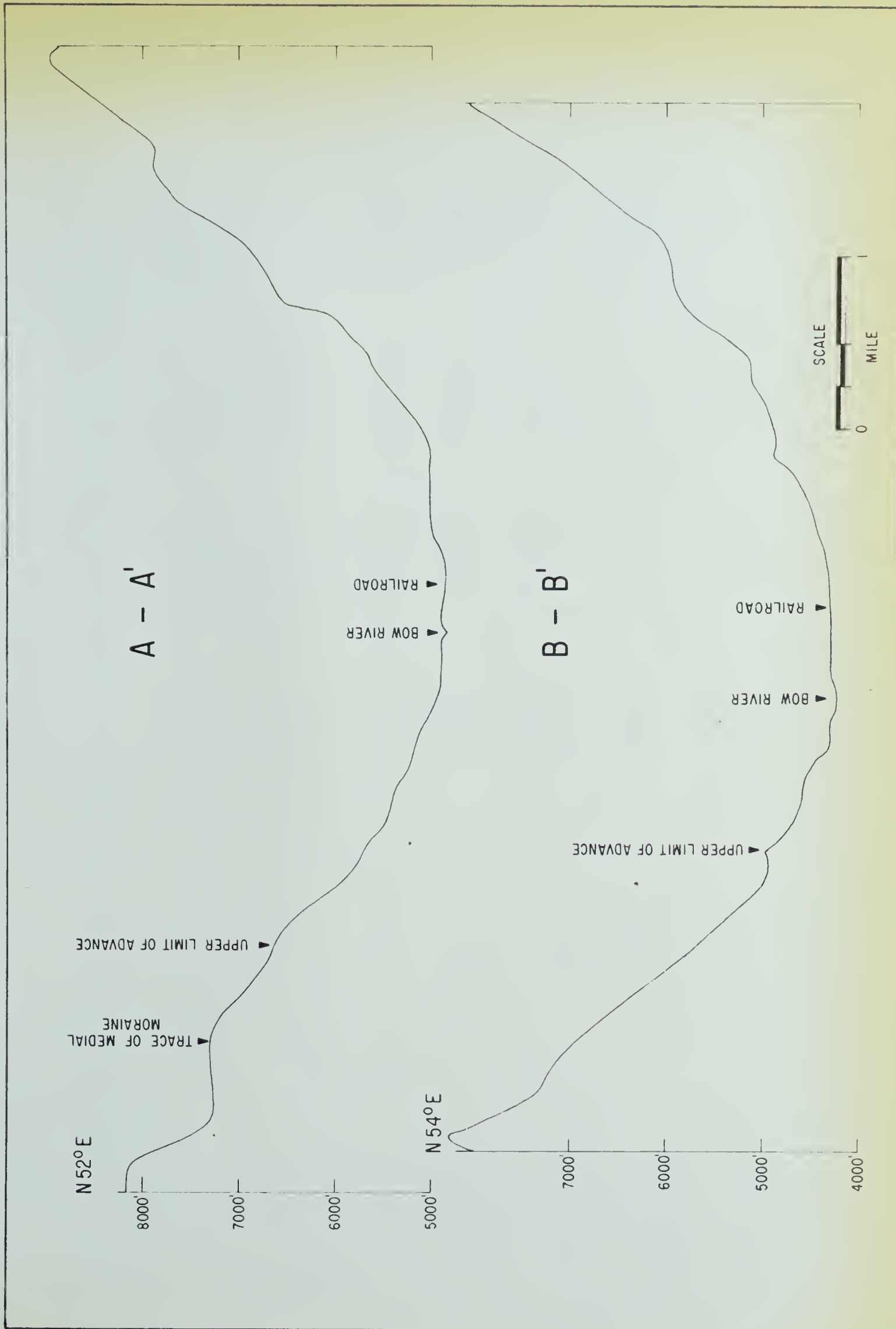


Figure 7. Topographic cross sections across the Bow River valley, showing breaks in slope caused by different glacial advances. Position of sections indicated on Maps 1 and 2.

TABLE VI

Data concerning indicators of upper limits of glacial advances or equilibrium phases and approximate ice thicknesses in the Major Valleys. The maximum and minimum elevations refer to the same break in slope or lateral moraine, but in different locations.

Location	Length of break in slope or lateral moraine (miles)	Maximum elevation (feet)	Minimum elevation (feet)	Reliability of data	Approximate ice thickness (feet)
Northwest side The Valley of the Ten Peaks	4 1/2	7,500	6,000	very good	1,050
West side Panorama Ridge	3	7,100	6,850	very good	600
Southwest side Bow River valley	7	6,750	6,200	very good	1,900 1,500
West side Baker Creek valley	min. 2 3/4	6,900	5,500	good	1,100
East side Baker Creek valley	1 3/4	6,700	6,400	fair	1,100
East side Baker Creek valley	1/2	7,000	6,600	fair	1,800

Same advance or equilibrium phase

TABLE VI - continued

Location	Length of break in slope or lateral moraine (miles)	Maximum elevation (feet)	Minimum elevation (feet)	Reliability of data	Approximate ice thickness (feet)
East side Baker Creek valley	1 3/4	6,400	6,200	fair	900
East side Baker Creek valley	1/2	6,300	6,200	fair	1,000
Northeast side Bow River valley near Eldon	1	6,700	6,200	good	1,650
Northeast side Bow River valley near Eldon	1/2	6,200	6,100	good	1,350
West side Baker Creek valley	min. 1 1/2	6,400	6,000	fair	500

Same advance or equilibrium phase

TABLE VI - continued

Location	Length of break in slope or lateral moraine (miles)	Maximum elevation (feet)	Minimum elevation (feet)	Reliability of data	Approximate ice thickness (feet)
Near Redearth Creek south- west side, Bow River valley	3/4	5,700	5,600	good	1,100
Park boundary southwest side Bow River valley	1 3/4	5,300	5,000	very good	750
Near Canmore southwest side Bow River valley	1	4,950	4,800	very good	500
Near Canmore southwest side Bow River valley	2 1/4	5,100	4,700	very good	750

Same advance or
equilibrium phase

Glacial Depositional Features

The entire Bow River valley floor, except for the floodplain and a few minor areas, is covered with a blanket of till and glacio-fluvial deposits. Instead of landforms characteristic of each variety of deposit, the deposits grade into one another with little or no apparent landform change. The surface features of the deposits, whether bedrock controlled or not, generally display structures parallel or nearly parallel to the long dimension of the valley. However, there are variations in these structures because of different origins.

From the northwest limits of the area to about 4 miles northwest of Eisenhower Junction is a series of low, rolling, parallel ridges separated by shallow depressions which are sharply marked by being forest free zones (Plate IV). They resemble forms somewhere between glacial flutings and drumlins. Often the up valley portion of the ridges has a greater local relief than the lower end. In the area under discussion, most of these structures are found on till and are not bedrock controlled.

Farther down the valley near Eisenhower Junction on the south side of the Bow River, the morphology changes from one of ice moulding to one of side glacial stream erosion and deposition (Plate V). A series of fairly straight and partially ridged "steps" are located between the valley floor and the wall. Similar features are found on the north side of Boom Creek valley. It is difficult to inspect the composition of the ridges because of the forest cover, but they are probably sorted glacial deposits formed by side glacial streams reworking till during a glacier retreat. Down cutting is significant in places, as evidenced by depressions between ridges and steps. Near Eisenhower Junction, these prominent steps grade into ice-contact fluvial deposits which are partly dissected by channels.

From Eisenhower Junction to about Banff townsite, bedrock knobs and ridges, covered with thin sheets of glacial drift, form the main irregularities on the floor of the Bow River valley. The topography is modified by crosscutting stream

channels.

Near Banff townsite, northeast of Tunnel Mountain, parallel ridges similar to those mentioned previously in this section occur on the surface of thick till beds. However, the ridges here are broader and longer (Plate VI). The lineation continues sporadically in the till, paralleling the valley from Tunnel Mountain to Gap. In some areas these ridges may reflect the bedrock morphology, although it is difficult to determine this because in most cases the bedrock strikes parallel to the till structures.

From Gap to the end of the Major Valleys physiographic unit, the Bow River flows across the regional strike of the bedrock, with bedrock knobs and ridges reflected through glacial deposits.

In this entire physiographic unit, past and present post-glacial streams have modified the morphology of glacial and glacio-fluvial deposits by eroding irregular crosscutting channels.

Non-Glacial Features

The Bow River is a subsequent stream for most of its length, but it cuts across the regional strike of the bedrock near Banff townsite and again near Gap. Whether this crosscutting indicates an antecedent, superimposed, or another type of stream is difficult to determine. It is, however, a pre-glacial feature (Maps 1, 2, and 3).

From the northwestern part of the area downstream to Massive, the river meanders only slightly, its floodplain is gravel-covered and varies in width between about one-third and three-quarters a mile. The average gradient in this 20 mile distance is 20 feet per mile. No bedrock can be seen within the channel, although there appear to be "islands" of bedrock within the floodplain southeast of Eisenhower Junction.

From Massive to the end of the study area at Seebe, a distance of about

45 miles, the gradient averages only 5.5 feet per mile. The river meanders widely and is partly braided, with the width of the floodplain averaging about 1 mile. The floodplain is very narrow or absent in a few places where the river flows on bedrock. Alluvial fans extending from the mountains control the position of the main channel in several places. Lakes occur in the floodplain in a few localities.

The change in stream characteristics between the two areas discussed is important stratigraphically because it is used as evidence indicating a relatively recent glacial advance down the Bow River valley to about Eisenhower Junction.

A major terrace above the present Bow River floodplain is present east of Banff townsite. It consists of outwash probably formed after glaciers had retreated far up their valleys. Other terraces of low relief above the Bow River were formed by recent changes in the Bow River regimen.

Drainage into the Bow River Valley is by high gradient streams with no floodplains or by low gradient tributaries with floodplains, some with hanging valleys. Off the lips of these hanging valleys or beyond the recently glaciated surfaces, streams form deep, narrow canyons as far as the Bow River floodplain. Outstanding examples are Johnston Canyon, Sundance Canyon, and the lower part of Redearth Creek.

Altrude Creek is somewhat of an anomaly. The creek flows from the Continental Divide in the only U-shaped valley that crosses the Divide in the study area. It appears that glaciers originating in cirques on the western side of the Divide have contributed to the east side or else the Divide has shifted eastward. After the recession of the last glacier, Altrude Creek was able to form a canyon approximately 500 feet deep. This occurred late in the glacial history, since meltwater channels from the last major glacial advance in the Bow River valley have been truncated by it.

Former meltwater channels are indicated on Maps 1, 2, and 3. Major lakes in the Major Valleys physiographic unit fall into two categories, glacial and

non-glacial in origin. In the former, only rock basin lakes occur; these are Lake Minnewanka and two tarns-Consolation Lakes. Lakes of non-glacial origin are Smith Lake, which is trapped in a former meltwater channel, and the Vermilion Lakes and Lac des Arcs, which are floodplain lakes. Moraine, Eiffel, and Lizard lakes are dammed by landslides, and Gap Lake, Two Jack Lake, Johnson, and a reservoir and unnamed lake near Canmore are artificial.

Superimposed upon and truncating glacial deposits are numerous well developed alluvial fans actively forming in the Bow River valley from small tributary creeks, both perennial and intermittent. In size the alluvial fans vary considerably; several are more than 1 1/2 miles wide. Northwest of Massive, alluvial fans are less developed, being smaller than for similar sized drainage areas found southeast of this area (Maps 1, 2, and 3). The similarities of the two areas in the resistance of bedrock to erosion, amount of run-off, vegetation, and local gradient support the conclusion that the relative length of development time for the fans in the two areas is different. This is evidence that the northern area has been more recently glaciated.

Mass-wasting processes are active in the Major Valleys physiographic unit. The most important products of these processes are landslides and talus. Rock-talus-and-soil-creep are also active throughout this region.

Landslides are indicated on Maps 1, 2, and 3. Of the fairly recent slides, one stands out in particular, although in part it is a result of sliding, slumping, and perhaps fluvial erosion. It is located near Johnston Canyon, and covers an area of about 2 1/2 square miles, consisting of irregular mounds similar to typical knob and kettle topography. Broad, arcuate slip faces occur in places. The slide is post-glacial in age, as evidenced by the fresh morphology and lack of till on the surface.

Fresh talus slopes with a present high rate of development are scarce. Only in the higher areas near timberline, such as in the Moraine Lake-Consolation Lakes areas are they formed. However, talus slopes with vegetation and a slower

rate of development are common on the steeper slopes of the main valleys. In fact, in places they have completely covered lateral moraines.

Two areas of sand dunes with distinctive topographic expression are present. One area of about one-third square mile, situated on glacio-lacustrine deposits, is located 2 miles northeast of Banff townsite. The dunes consist of irregular, low relief mounds formed by downvalley winds and are stabilized today by vegetation. An area of similar dunes is adjacent to Lac des Arcs. These dunes form strips and patches along the banks of the Bow River and on islands south of the main channel. Although the dunes are partially stabilized by vegetation today, wind is still shifting sand due to the fluctuating water level of the Bow River, which exposes fresh material at certain times during the year. The total area involved here is not more than one-half square mile.

Kame Moraine Region

General Statement

This area, arcuate in shape, is a relatively flat plain with low, irregular mounds, ridges, and terraces extending from Kananaskis to Seebe. The plain has an average elevation of approximately 4,350 feet and is essentially an area of aggradation (Map 3).

Glacial Erosional Features

Near the boundary of the plain and the Front Ranges are several prominent knobs, three of which are drumlins. The local relief of the knobs is in most cases over 100 feet, while lengths are from about one-third to one mile and maximum widths about 700 feet to one-third mile. Although they are covered with surficial deposits, the knobs that are not drumlins are probably bedrock cored, as implied by the disharmonious shapes and proximity to bedrock outcrops.

Glacial Depositional Features

The striking features of this area are ice-contact fluvial deposits, consisting of kames, eskers, and crevasse fillings? (Plate VII). It is difficult to distinguish between the kames, eskers and crevasse fillings? because of superimposition and intergrowth between the features. The best developed esker, located just east of the Kananaskis River, is approximately 150 feet wide and 1/4 of a mile long. Surrounding these topographic features are outwash gravels, which sometimes form low terraces with scarps only a few feet high.

Non-glacial Features

The Bow River in this area has incised itself into bedrock, having a discontinuous and narrow floodplain, which suggests that the channel is relatively young. A well developed set of recent terraces is present along the Kananaskis River.

Alluvial fans and landslides are located on the lower parts of the mountains bordering this physiographic unit. A series of three indistinct bedrock terraces covered with glacial material are near the southern boundary of the area. Also a major meltwater channel is present in the same area. Its direction of gradient is toward the valley of the Kananaskis River, indicating that the ice at the head of the channel was at least 200 feet thick at one time.

A few lakes are present most of which are moraine dammed.

Conclusions

The physiography of the area, yields important clues on glacial geology that can be utilized to decipher the Quaternary history and stratigraphy.

The more important facts are:

1. Cirque levels indicate at least three periods of glacier development.
2. Lateral moraines and glacial scouring (breaks in slope) suggest definitely four and possibly five glacial advances or equilibrium phases.
3. Small glaciers which extended beyond their cirques on a previously

glaciated surface indicate a later, less extensive advance.

4. The morphology of the terrain up-stream from Eisenhower Junction and the ice-contact fluvial complex at Eisenhower Junction indicate that this area has been more recently glaciated than the area downstream.

CHAPTER 3 - BEDROCK GEOLOGY

General Statement

For convenience, the region under study is divided into two geologic zones (Map 4): Zone A, Kananaskis River to Eisenhower Junction (Front Ranges sub-province), and Zone B, Eisenhower Junction to Moraine Lake (Main Ranges sub-province).

The information presented in this chapter is taken from the guidebooks of the Alberta Society of Petroleum Geologists (1956, 1963) unless otherwise indicated.

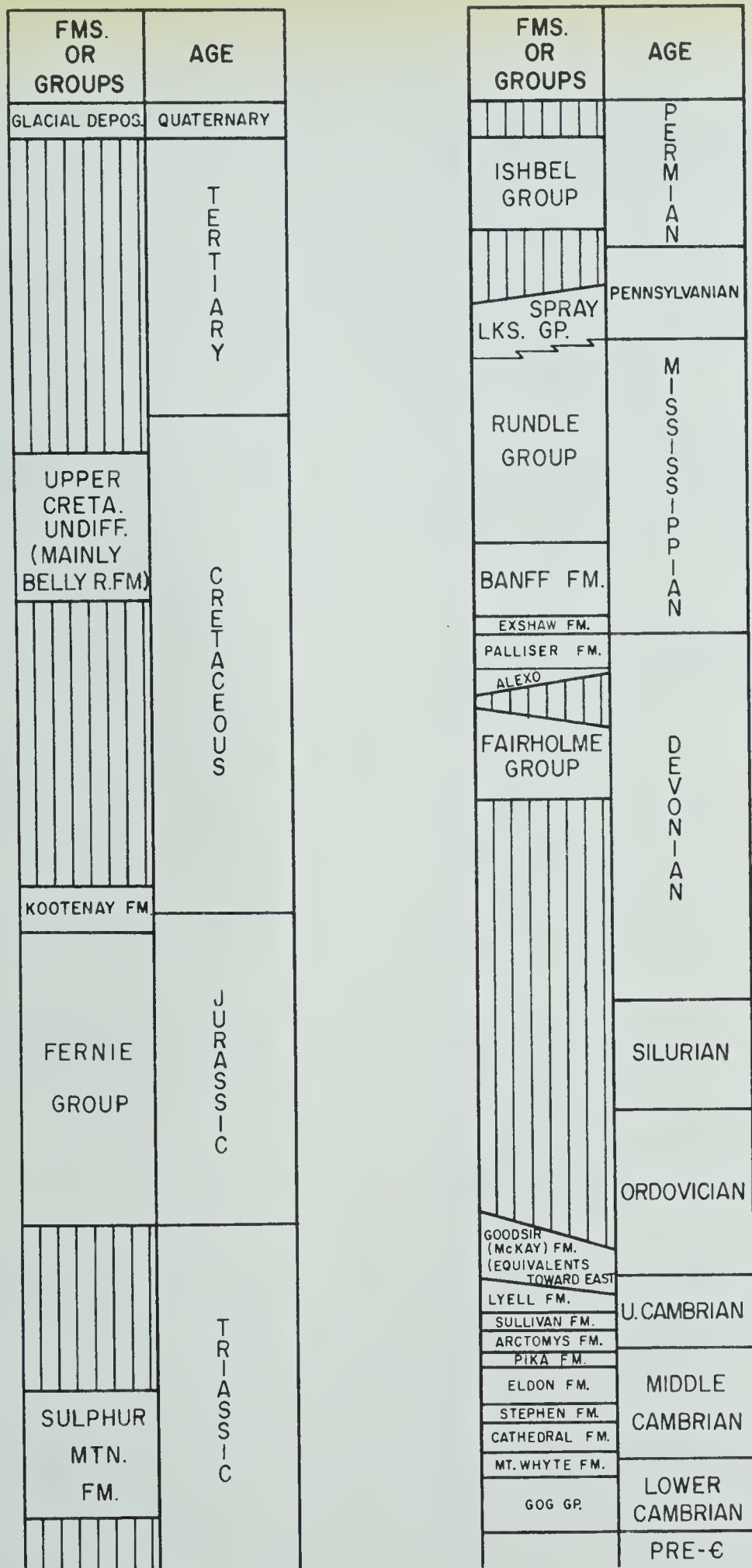
Stratigraphy

There are, in the study area, over 12,000 feet of sedimentary rocks, mostly Paleozoic in age. No large bodies of igneous rocks are known, although there is mineralization along fractures in places, as well as sills northwest of Eisenhower Junction (A. Akehurst, personal communication). To the north, beyond the area under investigation near Bow Lake, there is a diabase dike that can be traced for 4,200 feet across the Bow River valley (Smith 1963, p. 65). The Ice River complex, consisting mainly of nepheline syenite crops out about 15 miles west of Eisenhower Junction.

In Zone A, Devonian and Mississippian rocks consisting principally of resistant dolomite and limestone are volumetrically the most important. They form the major mountain ranges. The major valleys are floored by weaker Mesozoic rocks composed predominantly of fine-grained clastics.

The principal rocks of Zone B are Cambrian dolomite and quartzitic sandstone. Three varieties of rocks found in till from this zone are especially useful as indicators of provenance of till. These include Lower Cambrian quartzitic sandstone, Precambrian pebble conglomerate, and Precambrian reddish and greenish shale (argillite).

Figure 8 illustrates the stratigraphic column of the Banff area and vicinity.



STRATIGRAPHIC COLUMN OF THE BANFF AREA.

Figure 8.

The general lithology consists of the following:

Upper Cretaceous undifferentiated: (mainly Belly River Fm.)	Mainly carbonaceous sandstone, light gray with shaly coal seams and shale, and minor siltstone and conglomerate. 2,000 feet <u>±</u> .
Kootenay Formation (Jurassic-Cretaceous)	Mainly shale, dark gray to black, usually silty or sandy; some carbonaceous shale, some coal; also conglomerate, sandstone, and siltstone. Up to 3,300 feet.
Fernie Group: (Jurassic)	Mainly shale, dark gray, brown to black, commonly sandy, calcareous and occasionally slightly bituminous; also phosphatic shale; minor limestone and sandstone. 1,600 feet <u>±</u> .
Sulphur Mountain Formation (Triassic)	Mainly shale, dark gray to black, calcareous or dolomitic; also limestone and dolomite; some nodular limestone. 600 to 2,400 feet.
Ishbel Group: (Permian)	Upper part - mainly chert, sandstone, and siltstone; also silicified phosphatic carbonate and conglomerate. Lower part - mainly shaly siltstone; also silty carbonate; black spicular chert and phosphatic siltstone. 400 feet <u>±</u> .
Spray Lakes Group: (Pennsylvanian-Mississippian?)	Upper part - dolomite, gray, silty; also chert breccia, nodular chert. Lower part - mainly sandstone and quartzite, medium-grained, buff weathering with cherty zones; some dolomite, fine to medium-grained, light gray to buff weathering. 450 feet <u>±</u> .
Rundle Group: (Mississippian)	Limestone, thick-bedded to massive, light gray to dark gray, coarse-grained alternating with limestone, dark gray to black, fine-grained with or without chert nodules. Up to 2,431 feet.
Banff Formation: (Mississippian)	Mainly shale, dark gray to black, calcareous, brown weathering; also limestone. Up to 1,489 feet.
Exshaw Formation: (Mississippian)	Shale, black, fissile; upper part calcareous, lower part non-calcareous. Up to 75 feet <u>±</u> .

Palliser Formation: (Devonian)	Upper part - limestone, black, fine-grained with pyrite nodules. Lower part - dolomitic limestone, gray mottled. Up to 1,000 feet $\pm$.
Alexo Formation: (Devonian)	Mainly silty dolomite, argillaceous; some dolomitic siltstone, mudstone, and quartzose sandstone. 100 to 300 feet.
Fairholme Group: (Devonian)	Upper part - dolomite, light gray, fetid. Lower part - dolomite, black, fine-grained, bituminous, fetid. Up to 1,900 feet.
Goodsir (McKay) Formation: (Equivalents in eastern part of area) (Ordovician-Cambrian)	Mainly limestone, gray, thin-bedded, argillaceous; also intraformational limestone conglomerate and shale, and cherty dolomite. 6,040 feet $\pm$ on Mount Goodsir.
Lyell Formation: (Upper Cambrian)	Magnesium limestone, dark and light gray, massive-bedded. 850 feet $\pm$.
Sullivan Formation: (Upper Cambrian)	Upper part - limestone, gray, hard, thinly-bedded. Lower part - mainly shale, arenaceous. Less than 1,440 feet.
Arctomys Formation: (Upper-Middle Cambrian)	Upper part - limestone, bluish-gray, finely laminated. Lower Part - shale, calcareous, arenaceous; and interbedded laminated limestone. Less than 1,386 feet.
Pica Formation (Middle Cambrian)	Limestone and dolomite, light to dark gray, blue-gray, buff, fine-grained, conglomeratic bands and shale partings. Up to 550 feet.
Eldon Formation: (Middle Cambrian)	Dolomite, pale pink to buff, white, unbedded; some parts coarse, vuggy, hematitic, and petroliferous. 1,400 feet $\pm$.
Stephen Formation: (Middle Cambrian)	Upper part - limestone, black-gray, finely crystalline to fine-grained, thin-bedded. Middle part - shale, gray to greenish, siliceous, calcareous. Lower part - limestone, dark gray, fine-grained to medium crystalline, thin-bedded, argillaceous. Up to 500 feet.
Cathedral Formation: (Middle Cambrian)	Mainly dolomite with some limestone; at Mt. Stephen contains siliceous shale and argillaceous limestone. Average 1,000 feet.

Mt. Whyte Formation: (Middle-Lower Cambrian)	Upper part - interbedded limestone and shale. Middle part - mainly shale, green; with sandstone and conglomerate. Lower part - mainly limestone, arenaceous; with pebbly sandstone and shale partings. 275 feet $\pm$.
Gog Group: (Lower Cambrian)	Mainly quartzitic sandstone, gray, white, brownish, purplish, and pink; few bands of siliceous shale. 2,000 feet $\pm$.
Precambrian:	Shale, greenish, reddish, and purplish, sandy and siliceous; two conglomerates, one quartz pebble, the other pink limestone. Up to 2,150 feet.

(Sources for the lithologic descriptions of formations and groups from Alberta Society of Petroleum Geologists, 1954, 1960, 1963, 1964).

Structure

In Zone A, the dominant structural features are a series of roughly parallel, northwest trending thrust faults. The McConnell fault separates this zone from the Foothills sub-province, and the Castle Mountain fault forms the eastern boundary of the Main Ranges sub-province (Zone B). Essentially all of the mountain ranges have a fault at the base of their northeast exposure as a result of resistant Paleozoic sedimentary rocks overriding and truncating weaker and younger rocks. The faults have a southwest dip of 30 to 45 degrees near the surface and a vertical stratigraphic displacement of many thousands of feet.

The beds dip generally to the southwest at angles up to 45 degrees as a result of the thrusts disrupting overturned folds. Anticlines, synclines, and minor folds, sometimes overturned, are present.

Most of the mountains and major topographic lows display the same sequence of rock as a result of thrusting. An idealized sequence from top to bottom is as follows:

The major mountain ranges consist principally of:

Mississippian limestone and shale
(Rundle Group, Banff and Exshaw Formations)

Devonian dolomite and limestone
(Palliser and Alexo Formations, Fairholme Group).

The major topographic lows consist principally of:

Jurassic (in part Lower Cretaceous) shale and sandstone
(Kootenay Formation, Fernie Group)

Triassic shale, limestone, and dolomite
(Sulphur Mountain Formation)

Permo-Pennsylvanian sandstone, siltstone, chert, and dolomite
(Ishbel and Spray Lakes Groups)

Cambrian and Ordovician limestone and dolomite have been brought up by the Bourgeau fault at the northeast face of the Sundance Range, and Cambrian limestone and dolomite appear above the McConnell fault near Exshaw.

In Zone B, a belt of relatively undisturbed older rocks have been thrust upward and outward along the Castle Mountain fault. This includes the rocks of Mt. Eisenhower and the mountains to the west as least as far as the Continental Divide. The two major structures in the area are broad, northwest trending synclines on either side of the Bow River valley. Therefore in the topographic low, the floor of the Bow River valley, an anticline is present.

A representative sequence of the major rocks in this area occurs on the southwest face of Mount Eisenhower. These are from top to bottom:

Upper Cambrian limestone
(Lyell and Sullivan Formations),

Middle Cambrian dolomite
[Arctomys (in part Upper Cambrian), Pica, Eldon, Stephen, Cathedral Formations].

Lower Cambrian quartzitic sandstones
[Mt. Whyte (in part Middle Cambrian) Formation, Gog Group], and

Precambrian shales

The Bow River valley is floored with Precambrian material in Zone B.

CHAPTER 4 - COMPOSITION OF SURFICIAL DEPOSITS

Till

General Statement

Till is widespread throughout the area of investigation (Maps 1,2, and 3). Individual till sheets, regardless of their ages, are difficult to separate from each other because of the similarities in texture, lithologic composition, and structure. These similarities are the result of the common place of origin of the glaciers and common directions of flow. Till differences are mostly a reflection of the composition of local bedrock. Vertical stratigraphic sequences with more than one till sheet are rare, and correlation aids, such as soil development or weathering characteristics of pebbles could not be used. Therefore, tills deposited by different advances are identified through their relationships with other glacial deposits and by geomorphic criteria.

In mapping, the till was subdivided into three units according to the degree of modification since deposition and not according to age (Maps 1,2, and 3). The steepness of the slope controls this modification, which includes slope washing and masking by colluvium. The three units were delineated by means of air photograph interpretation.

Later, the tills were subdivided according to relative age into Tills A, B, Bow valley, and Eisenhower Junction, by utilizing other geologic information (Map 5). A description of the tills based upon undisturbed samples within the Bow River valley follows.

Field Descriptions

Till A: About 3 1/2 miles north-northwest of Canmore, a limited exposure of till, about 12 feet thick, crops out along a canyon wall cut at the base of a hill (Map 5, Plate II B). The hill apparently consists of glacial outwash over-

lying Till A. The lateral extent of the till and the material underlying it is not known. However, the till is believed to be one of the oldest in the area; the reason for this belief will be explained in the next chapter.

The till is firm, consisting of about 80% clay loam (see Figure 11 for texture nomenclature), the remainder being gravel-sized material. The clay loam is calcareous and light olive gray (5Y6/1). The gravel-sized components are mainly subangular to subrounded (Krumbein 1941). Some are striated, and many display a weak fabric resulting from granules, pebbles, and boulders being oriented with their long axes parallel, or nearly so, to the direction of glacier movement. The mode of the gravel-sized fraction is about 15 to 30 mm., while some boulders have diameters as large as 1 foot. Nearly equal parts of dolomite and limestone comprise about 80% of the gravel-sized material, and quartzite, quartzitic sandstone, and chert comprise most of the remainder.

Till B: At creek level about 1 1/2 miles southwest of Grotto Mountain is an outcrop of till about 65 feet high and nearly one-fifth mile long (Map 5). Although contacts with other deposits are not exposed, the till is probably bordered and capped by glacial outwash.

Till B is similar to Till A, except that about 65% of it is clay loam, and dolomite comprises nearly one-half of the gravel-sized material; the remainder is mostly limestone with lesser amounts of quartzite, quartzitic sandstone, and chert.

Bow Valley Till: The most widely distributed till in the area under investigation has been designated as the "Bow Valley Till." This till is, for the most part, present at or near the surface. Undisturbed Bow Valley Till is extensive in the form of ground moraine throughout the lower portion of the Bow River valley and its tributaries from near Eisenhower Junction to Exshaw (Map 5). On the valley walls the till, partly as lateral moraine, is modified by erosion. Thus, the upper limit of the advance that deposited the till is not defined by the till itself, but by geomorphic

features. The most extensive and thickest outcrops are located from the northeast side of Tunnel Mountain, in a roughly crescent shaped body, to the confluence of the Bow and Cascade Rivers. Good outcrops are also found on the southwest side of the Bow River near Canmore.

An outcrop (called the Powerhouse Section) with 103 feet of till exposed, is located on the southwest side of the Cascade River about half a mile southwest of the Banff powerhouse, and is informally designated as the type section for the Bow Valley Till (Appendix A, Section 1; Plate VIII). Although thicker till outcrops are present in this area, they are not as conveniently located. The thickness measured at this location is less than the original thickness, since erosion of the surface has removed some material. Outside this crescent-shaped area, Bow Valley Till is generally much thinner but continuous, except for some thick, restricted outcrops occurring on the downvalley side of truncated spurs.

Bow Valley Till usually forms the surface, although it is sometimes capped by patches of loess, wind-blown sand, washed gravel less than 4 feet thick or lacustrine deposits which were not mapped. However, thicker gravel and lake deposits which were mapped overlie the till near Banff circle on Route 1 (Maps 2 and 5; Figure 9). Glacial erosional ridges and depressions as discussed in Chapter 2 are extensive on the surface of the Bow Valley Till from Banff townsite southeast to the end of the outcrop area.

Most outcrops of Bow Valley Till do not include exposures of the underlying material. However, the sections northeast of Tunnel Mountain and near Canmore discussed above are underlain by thick deposits of outwash gravels, some believed to be the oldest glacial deposits in the Banff area (Maps 2 and 5; Plate VIII).

Downstream from Banff townsite on the northeast side of the Bow River valley to about 4 1/2 miles southeast of Canmore, a thin and discontinuous till sheet caps outwash deposits (Maps 2 and 5; Figure 10). This till was not mapped unless it was extensive. It has the same composition as the Bow Valley Till, as determined by

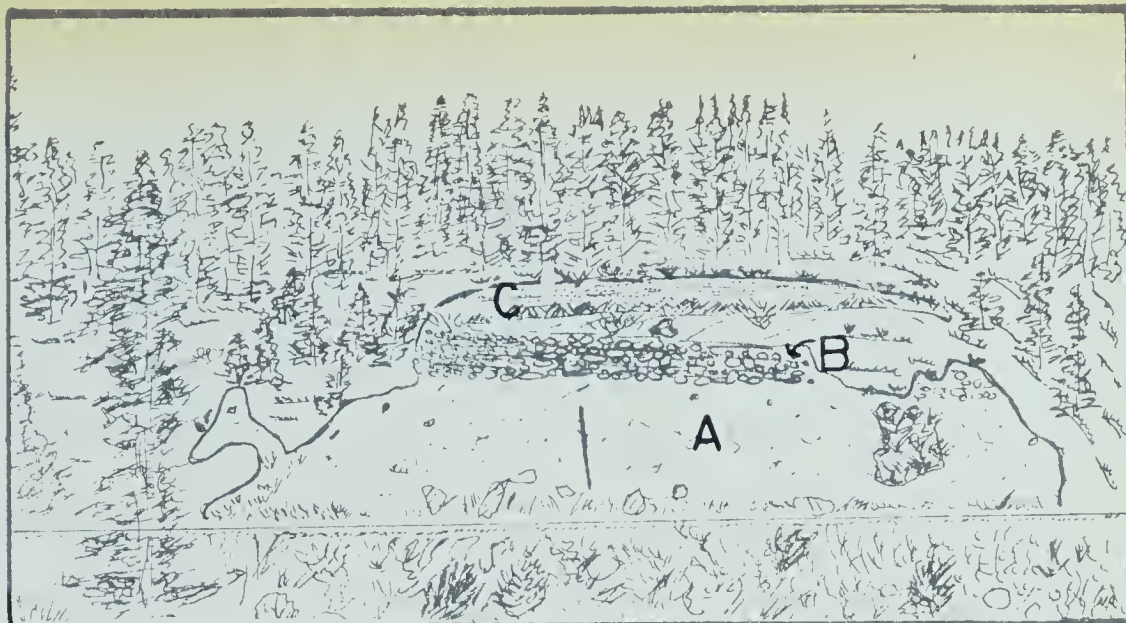


Figure 9. Bow Valley Till (A) underlying lake deposits (C) and outwash (B), about 2 1/2 miles northeast of Banff townsite on the southwest side of the Cascade River. View toward southwest. ($51^{\circ}12'30''$ N. latitude; $115^{\circ}31'40''$ W. longitude).

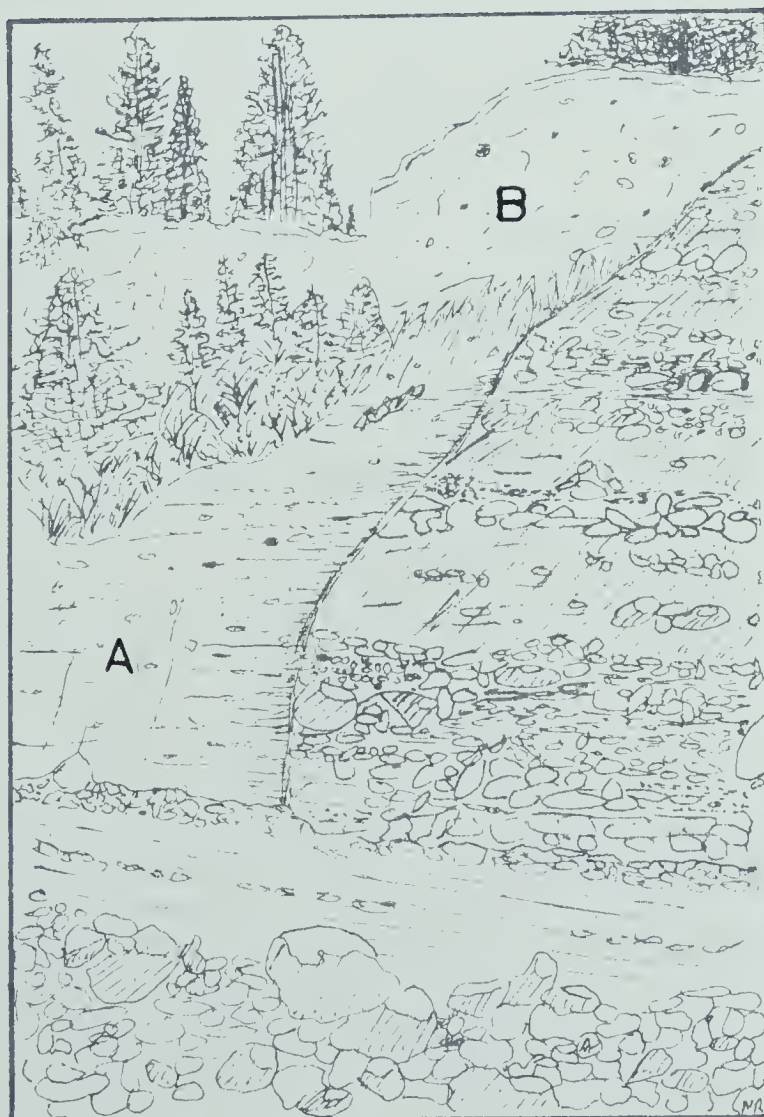


Figure 10. Bow Valley Till (B) deposited over outwash (A). Section about 1 1/2 miles east of Canmore. View toward southeast. ($51^{\circ}05'20''$ N. latitude; $115^{\circ}19'20''$ W. longitude).

field and laboratory examinations. It is not always possible to establish a stratigraphic relationship of this till to the adjacent outwash and the main body of Bow Valley Till; therefore, this till is also called Bow Valley Till.

Early in the study an attempt was made to sample and study the Bow Valley Till in such a way that ablation and lodgment till might be distinguished. It soon became apparent that in most areas this would be impossible to do with the time and equipment available, the limited exposures, and the similarity of till regardless of age. At the "type section," however, systematic study and sampling was possible. Unfortunately, from field and laboratory analyses, no separation could be made.

In the following description, a condensation of all field observations of Bow Valley Till is presented regardless of origin of the till.

Bow Valley Till is firm, with rare patches and lenses of silt, sand, and gravel. The gravel-sized fraction of the till comprises 5% to 30% of the total, with 20% being a rough average. The finer fraction is mostly a calcareous sandy clay loam, light olive gray (5Y6/1) where unoxidized and yellowish gray (5Y7/2) where oxidized. The gravel-sized material often displays a weak fabric caused by the long axes of particles being approximately parallel to the direction of glacier movement. The gravel fragments range from subangular to rounded, with most of the material being either subangular or subrounded. Striations are common and the modal diameter varies from 10 to 50 mm. Dolomite and limestone comprise most of the material in the coarse fraction, with lesser amounts generally of quartzitic sandstone, quartzite, chert, shale, and pebble conglomerate.

The provenance of Bow Valley Till (as well as Tills A and B) is indicated by the presence of pink Lower Cambrian quartzite, Precambrian pebble conglomerate, and Precambrian reddish and greenish argillaceous shale that outcrop in the northwestern part of the area under investigation (Map 4). Also, pebbles of altered basic igneous phaneritic rock believed to be derived from the Crowsfoot dike located near Bow Lake (Smith 1963) are found in rare instances. The only real value of these

indicators is their confirmation of the direction of flow of the glaciers.

Eisenhower Junction Till: A second major till sheet, in the form of ground and lateral moraine, is named the "Eisenhower Junction Till." This till is different in composition from the other tills discussed, because of its limited distribution over a distinctive type of bedrock (Maps 1, 4, and 5). However, the distribution limits were determined from stratigraphic relationships and geomorphic data and not by the distinctive lithology.

Undisturbed Eisenhower Junction Till is widely distributed in the lower part of the Bow River valley from Eisenhower Junction northwestward. It also occurs in Consolation Valley, The Valley of the Ten Peaks, and other tributary valleys of the Bow River valley northwest of Eisenhower Junction. Higher up the valley walls, the till becomes more and more modified by slope washing and masking by colluvium.

No "type section" was designated because of the limited exposures. The few good outcrops available are usually less than 20 feet thick. Eisenhower Junction Till forms at the surface and overlies bedrock directly, except for a small area near Eisenhower Junction where the till overlies ice-contact fluvial deposits (Plate IX A). Erosional ridges and depressions, as discussed in Chapter 2, caused by a minor re-advance, are present throughout the area covered by Eisenhower Junction Till. In the description that follows, only unmodified material found in the lower part of the Bow River valley is considered.

Eisenhower Junction Till is generally firm, containing from 10% to 35% gravel-sized material, the average being about 25% (Plate IX B). Most fine material is classified as a calcareous sandy loam, with some as calcareous clay loam. When the fine fraction is unoxidized, the color is light olive gray (5Y6/1); where it is oxidized, yellowish gray (5Y7/2). Pebbles and boulders are often striated and oriented with their long axes approximately parallel to the direction of glacier movement. The roundness of the gravel-sized fraction varies between angular and

rounded, with most material being subangular or subrounded. Quartzitic sandstone is the most abundant material in the gravel-sized fraction, followed by dolomite, shale, and limestone. Lesser amounts of pebble conglomerate, chert, and quartzite are present. Indicator pebbles similar to those described in the section on Bow Valley Till are found in abundance.

Laboratory Analyses

General Statement: Samples of till from thirty-five locations in the Bow River valley were selected for laboratory analyses. The till samples analysed are from undisturbed and unweathered sites, except where indicated. The sample locality map (Map 6) should be consulted before interpreting the data in the various figures and tables presented in the following sections.

Mechanical Analysis

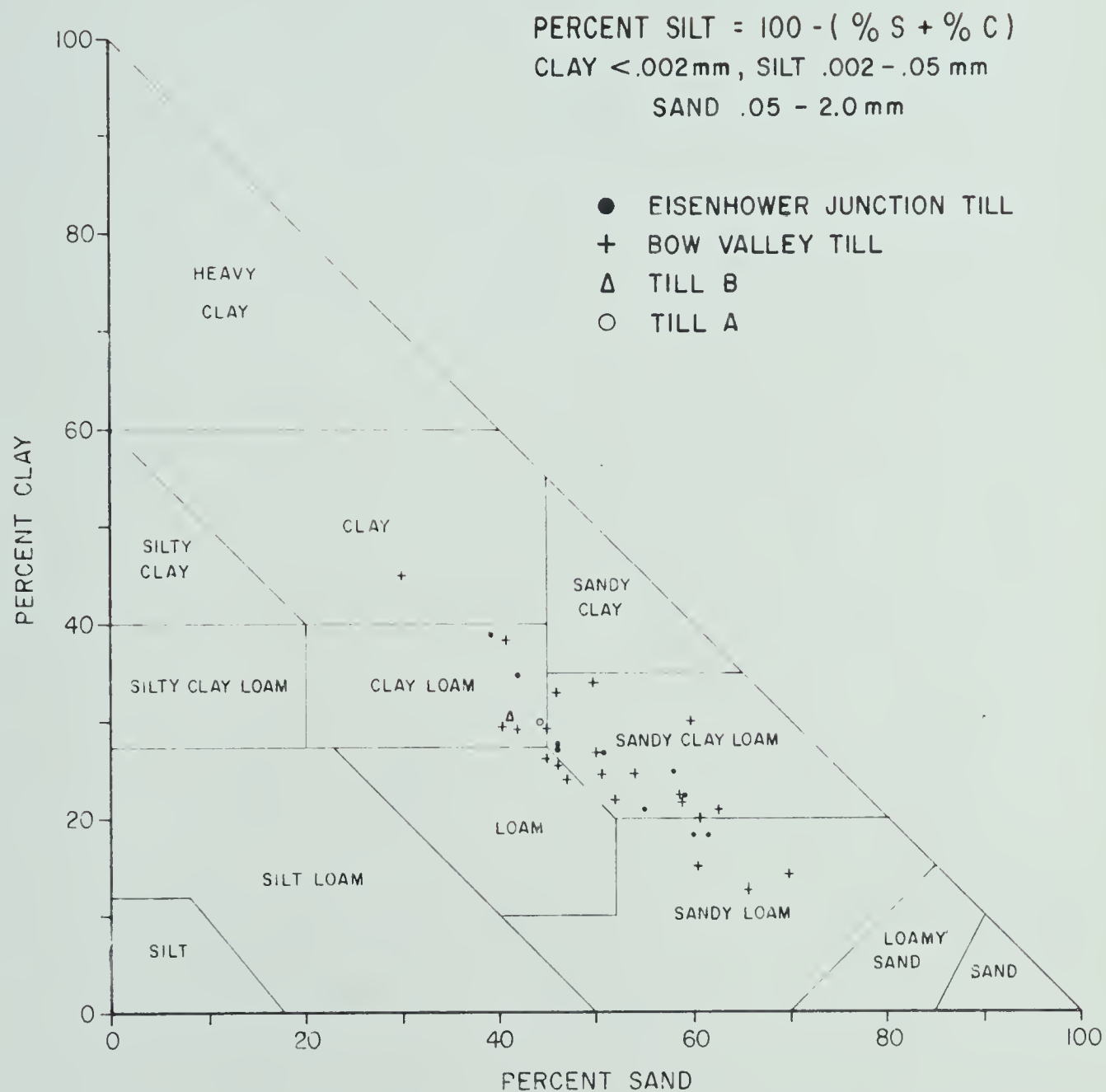
Method of investigation: Sand, silt, and clay percentages were determined by the hydrometer method on the finer than 2 mm. fraction of the till (Bouyoucos 1951).

Results: Most tills analysed fall within the definition of sandy clay loam (Table VII, Figures 11 and 12), with a few in the clay loam, loam, and sandy loam categories, and one in the clay category. Although too few samples of Tills A and B were analysed to allow the writer to draw positive conclusions, there are no distinctive differences in texture between the various till units. Certain ratios and percentages of size fractions are plotted against their positions in the Bow River valley in Figures 13 through 17. The results clearly indicate that there is no possibility of using grain size criteria in correlating or distinguishing different tills of the area. The writer is surprised that the data do not show a clear-cut textural difference between the Eisenhower Junction and Bow Valley Tills. The former is situated on and surrounded by bedrock generally different in composition from that downvalley

TABLE VII

Size distribution of the less than 2.0 mm. size fraction of till samples (minus carbonates).

Till	Sample Number	Clay %	Silt %	Sand %	Clay Silt+Sand	Sand Clay+Silt
Eisenhower Junction	N-20	18	20	62	.22	1.63
	N-27	18	23	59	.22	1.43
	N-32	22	26	46	.38	.85
	N-34	34	24	42	.51	.72
	N-35	39	23	38	.64	.61
	N-39	27	21	52	.37	1.08
	N-41	22	20	58	.28	1.39
	N-43	29	25	46	.40	.85
	N-45	21	23	56	.26	1.27
	N-159	26	18	56	.35	1.27
Bow Valley	N-48	28	22	50	.38	1.00
	N-50	29	27	44	.40	.78
	N-52	24	23	53	.31	1.12
	N-58	13	21	66	.15	1.94
	N-60	21	17	62	.26	1.63
	N-69	29	30	41	.40	.69
	N-74	45	25	30	.81	.42
	N-79	24	25	51	.31	1.04
	N-83	33	21	46	.48	.85
	N-85	26	27	47	.35	.88
	N-87	14	16	70	.16	2.33
	N-90	29	28	43	.40	.75
	N-92	16	24	60	.19	1.50
	N-94	20	19	61	.25	1.56
	N-118	30	10	60	.43	1.50
	N-120	23	19	58	.29	1.39
	N-121					
	(weathered)	35	16	49	.53	.96
	N-124	25	29	46	.33	.85
	N-136	23	25	52	.29	1.06
	N-144	22	20	58	.28	1.39
	N-146	27	28	45	.37	.81
	N-147	38	21	41	.61	.69
	N-149	26	28	46	.35	.85
Till B	N-114	32	26	42	.47	.72
Till A	N-106	30	26	44	.43	.78



TEXTURAL CLASSIFICATION USED BY SOILS DEPT, UNIVERSITY OF ALBERTA (AFTER J.A. TOOGOOD)

Figure II. Textural classification of tills of the less than 2.0 mm size fraction (minus carbonates).

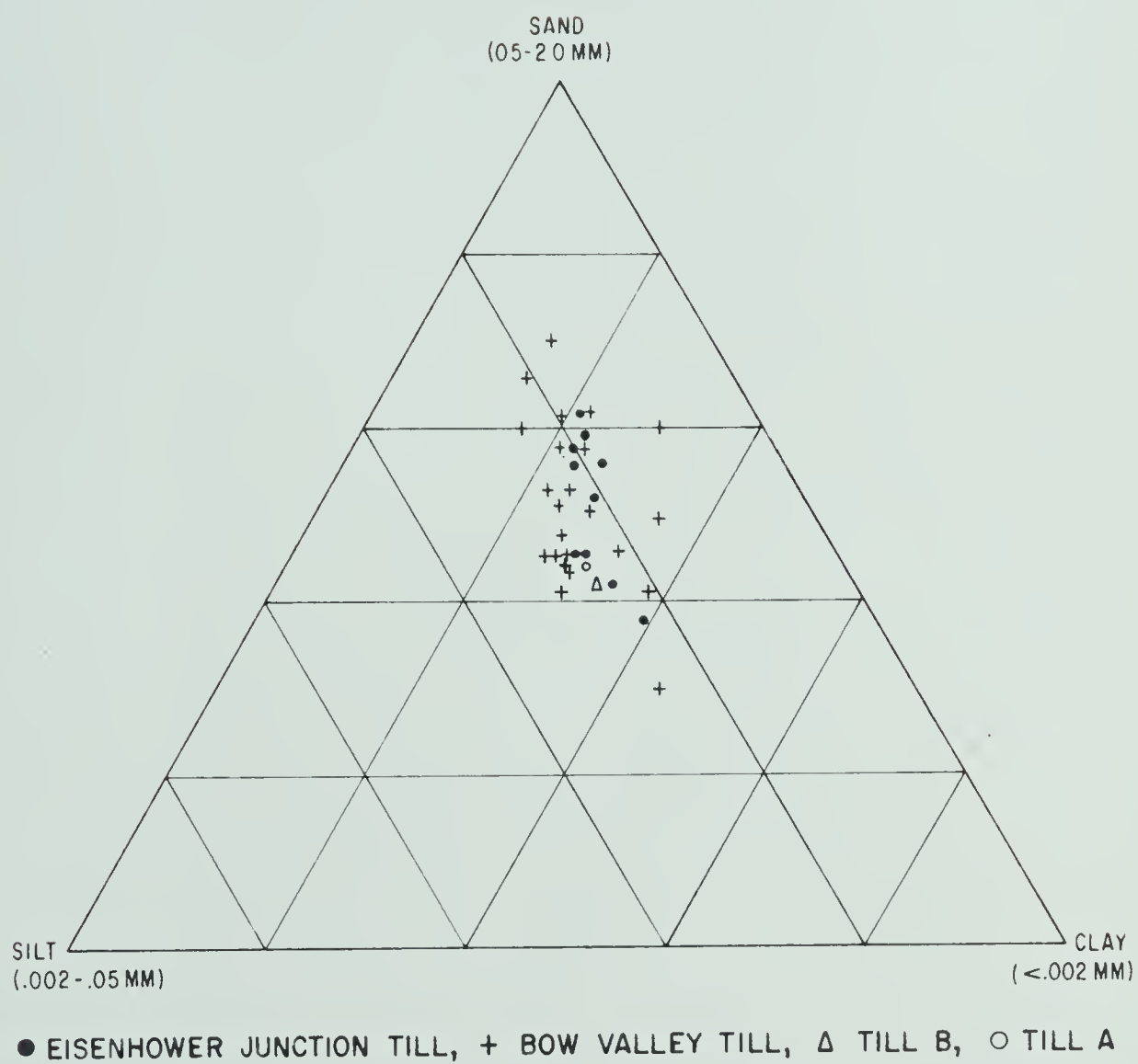
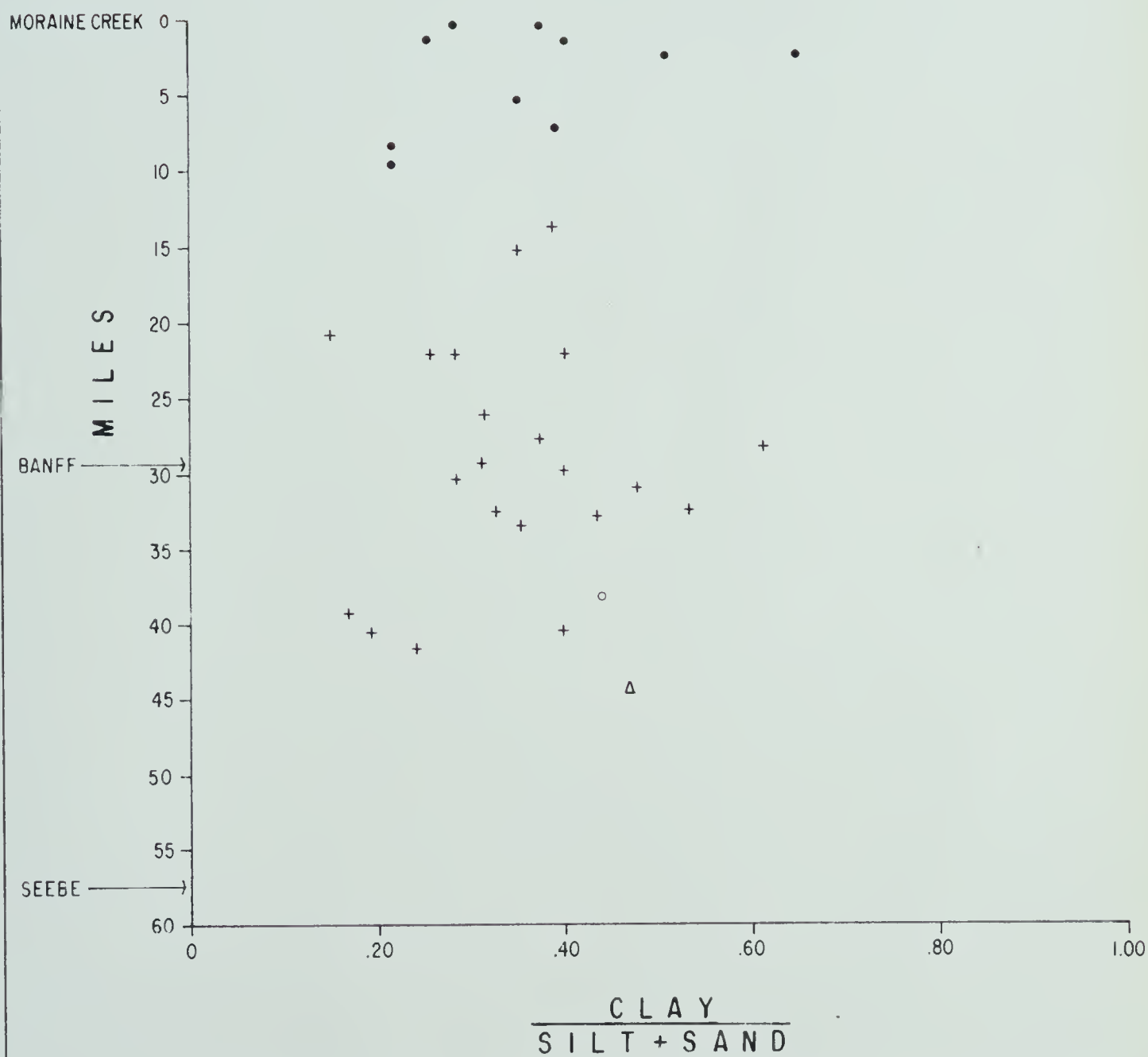


Figure 12. Texture of the less than 2.0 mm size fraction of various till samples (minus carbonates).



● EISENHOWER JUNCTION TILL, + BOW VALLEY TILL, Δ TILL B, ○ TILL A

Figure 13. Clay to silt plus sand ratios of the various till samples plotted against position in the Bow River valley (minus carbonates).

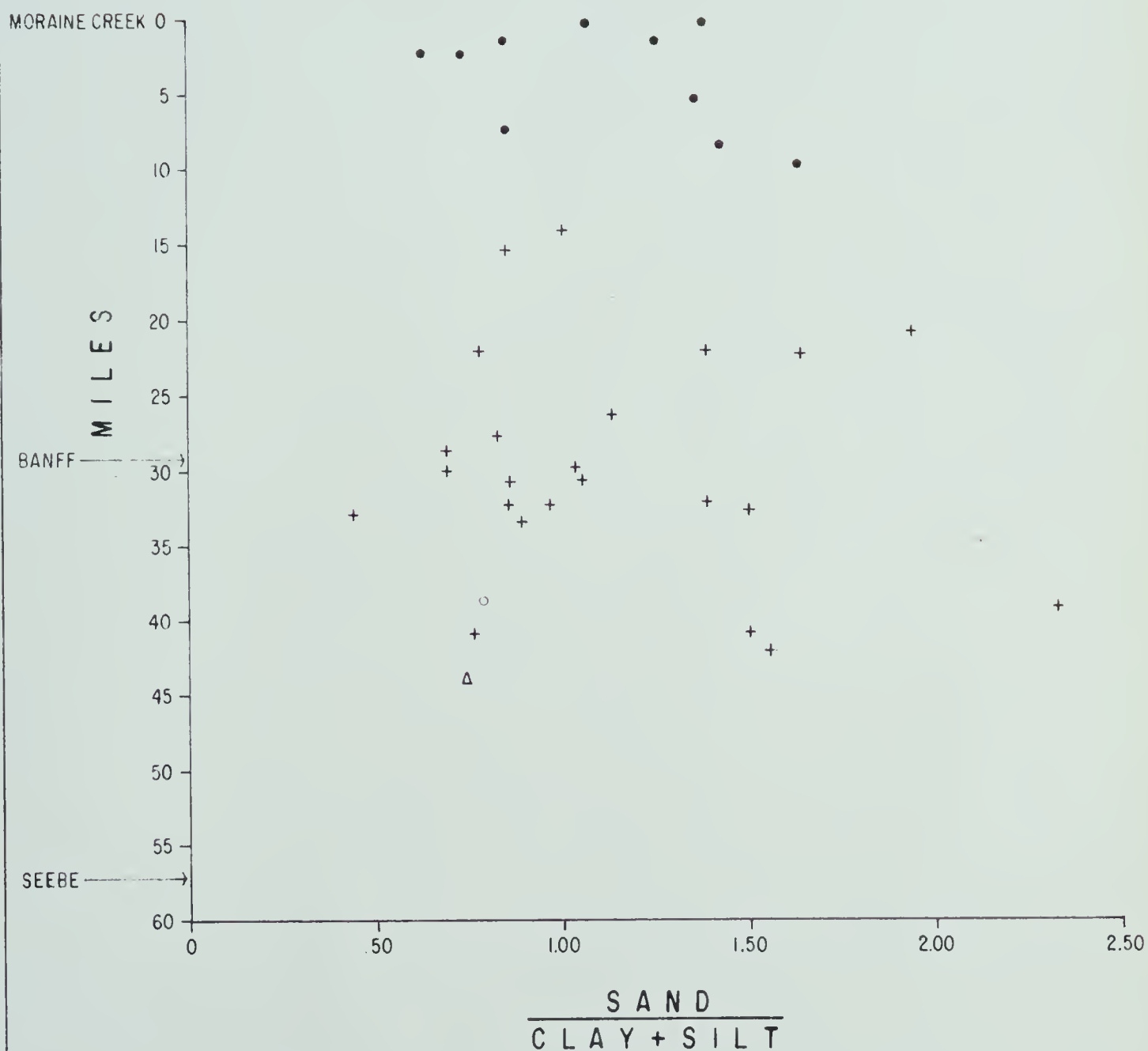
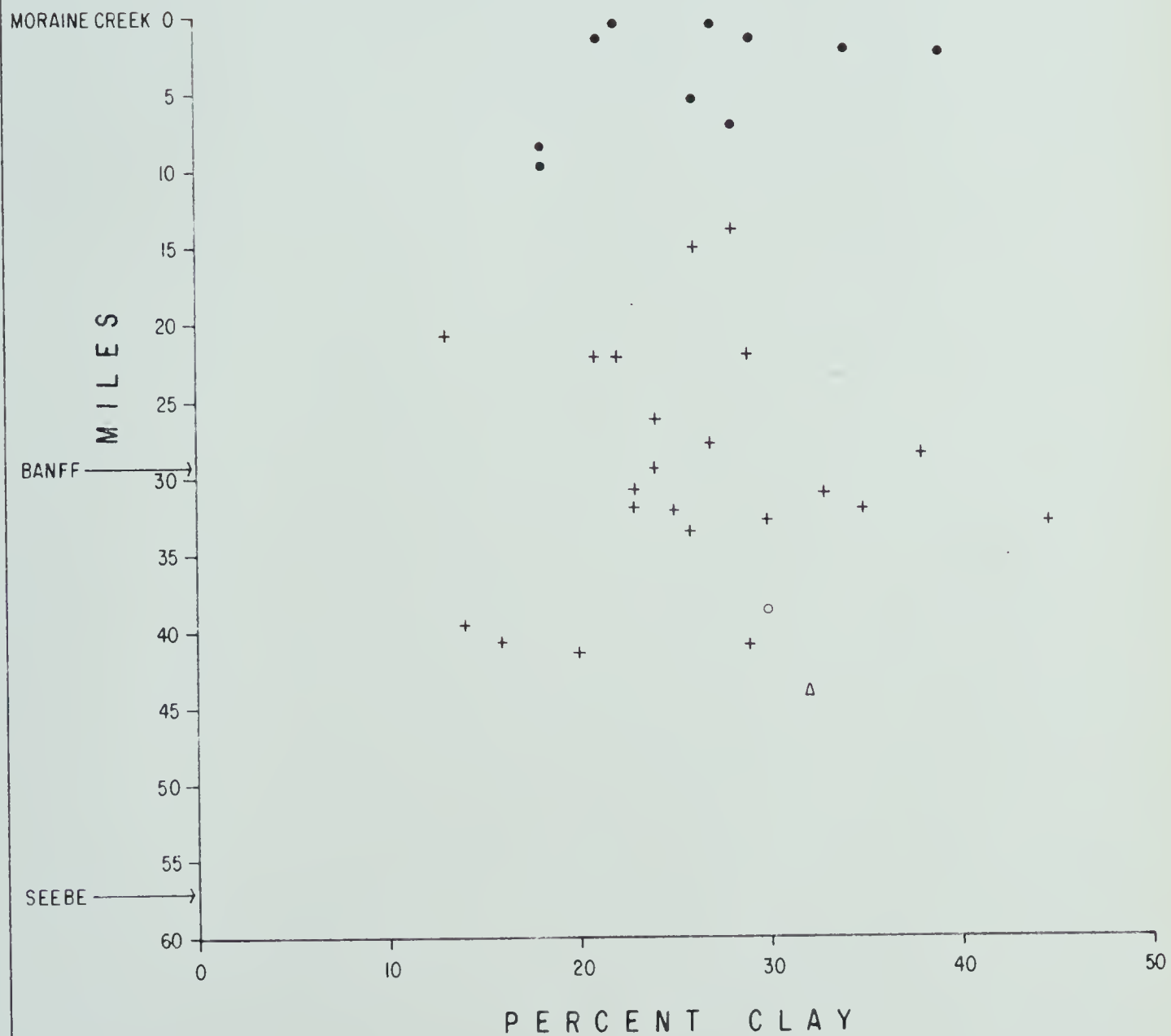
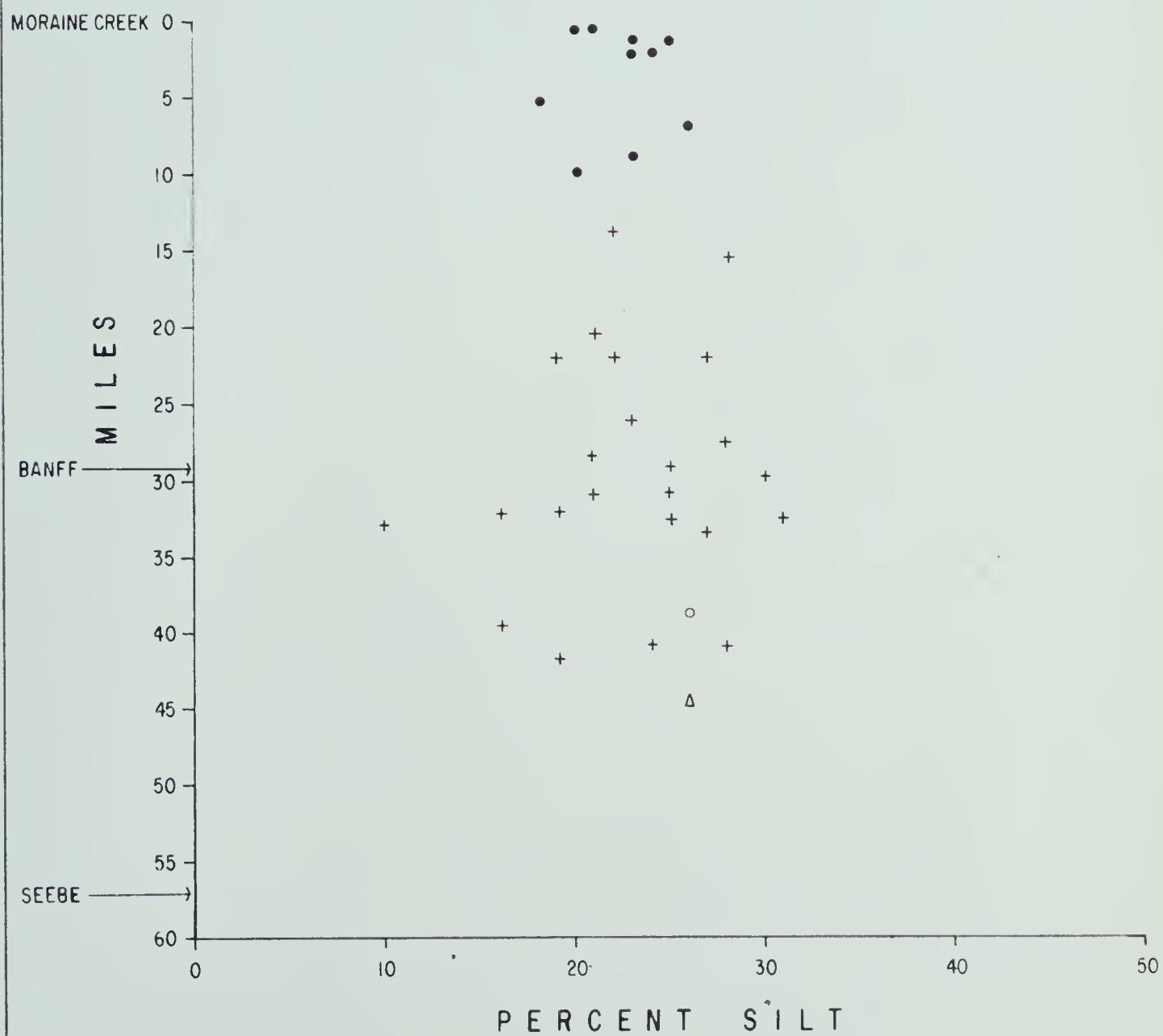


Figure 14. Sand to silt plus clay ratios of the various till samples plotted against position in the Bow River valley (minus carbonates).



● EISENHOWER JUNCTION TILL, + BOW VALLEY TILL, Δ TILL B, ○ TILL A

Figure 15. Percentage of clay-sized material of the less than 2.0 mm size fraction of various till samples plotted against position in the Bow River Valley (minus carbonates).



● EISENHOWER JUNCTION TILL, + BOW VALLEY TILL, Δ TILL B, ○ TILL A

Figure 16. Percentage of silt of the less than 2.0 mm size fraction of various till samples plotted against position in the Bow River valley (minus carbonates).

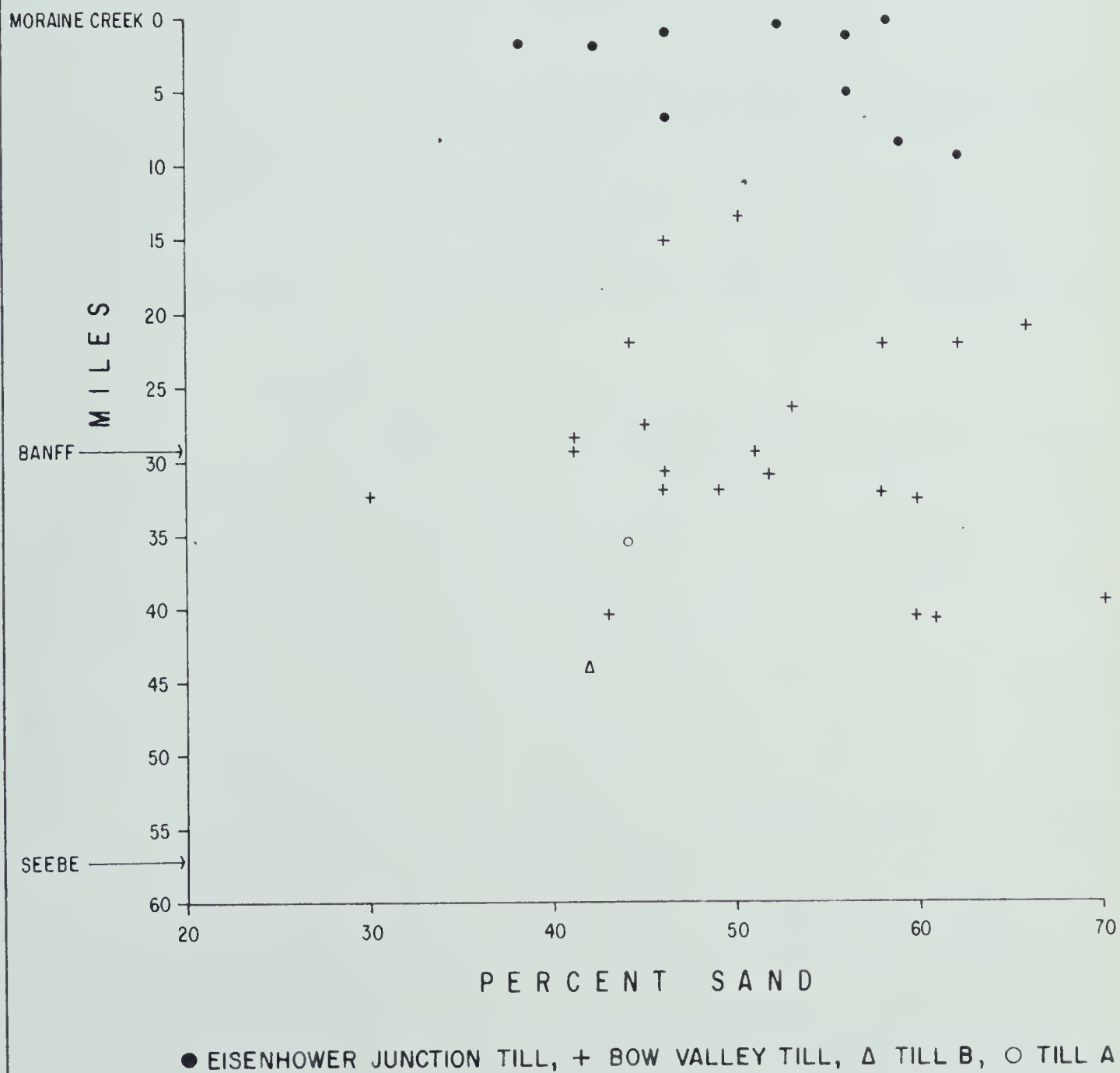


Figure 17. Percentage of sand of the less than 2.0 mm size fraction of various till samples plotted against position in the Bow River valley (minus carbonates).

from Eisenhower Junction on which the latter lies (Chapter 2; Map 4). Lack of a distinct difference may be the result of the total percentages of different size fractions in the two distinct bedrock areas being about the same, or of the wide range of relative proportions of a certain size fraction in each till masking any obvious differences.

Roundness

Method of Investigation: The roundness of each particle was determined for one hundred pebbles in each pebble count sample by using Krumbein's (1941) chart for visual roundness. These were then categorized according to lithology. The pebbles investigated range between 6 and 64 mm. in diameter.

Results: Table VIII shows the results of the roundness investigation. The average roundness lies generally between about .35 and .60 therefore, subangular to subrounded (Krumbein's nomenclature, 1941). (The number of pebbles considered for each figure is presented in Table X).

Plotting two rock types of different resistances against position in the Bow River valley (Figures 18 and 19) indicate that:

1. The less resistant rock, dolomite in this case, falls within the same range of roundness in the two major varieties of till.
2. There is no apparent increase in degree of average roundness in the dolomite pebbles downvalley.
3. In the Bow Valley Till at least, the quartzitic sandstone is as well rounded as the dolomite.
4. The quartzitic sandstone generally shows less rounding in the Eisenhower Junction Till than in the Bow Valley Till farther downvalley.

The results indicate that the distance of transport increases the roundness of the quartzitic sandstone. This concurs with Holmes¹ (1960) results. The source of

TABLE VIII

Average pebble roundness of pebble count samples*

Till	Sample Number	Precambrian Shale (Argillite)	Lower Cambrian Quartzitic Sandstone	Dolomite (mostly Paleozoic)	Limestone (mostly Paleozoic)	Other
Eisenhower Junction	N-26	.40**	.22	.20	.45	Precambrian pebble congl. .20
	N-31	.45	.44	.48	.55	Precambrian pebble congl. .25 Siltstone .40
	N-33	.51	.34	.36	.48	Precambrian pebble congl. .40
	N-38	.40	.34	.43	.44	Post-Precambrian chert, quartzite, or other .45
	N-40	.44	.35	.38	.45	Post-Precambrian chert, quartzite, or other .40
	N-42	.46	.40	.42	.49	Post-Precambrian chert, quartzite, or other .47
	N-44	.50	.39	.47	.55	Post-Precambrian chert, quartzite, or other .44 Shale .30
	N-158	.30	.36	.50	.48	Post-Precambrian chert, quartzite, or other .41 Phyllite .30
Bow Valley	N-47	--	.39	.49	.50	Precambrian pebble congl. .46 Post-Precambrian chert, quartzite, or other .37

TABLE VIII - continued

Till	Sample Number	Precambrian Shale. (Argillite)	Lower Cambrian Quartzitic Sandstone	Dolomite (mostly Paleozoic)	Limestone (mostly Paleozoic)	Other
	N-49		.51	.49	.45	Post-Precambrian chert, quartzite, or other .27
	N-51	.90	.42	.40	.43	Post-Precambrian chert, quartzite, or other .36 Shale .31 Precambrian pebble cong. .40
	N-53	--	.51	.59	.56	Post-Precambrian chert, quartzite, or other .45
	N-57	--	.42	.39	.38	Post-Precambrian chert, quartzite, or other .29
	N-59	--	.46	.41	.41	Post-Precambrian chert, quartzite, or other .34
	N-73	--	.42	.47	.48	Post-Precambrian chert, quartzite, or other .36
	N-78	.50	.49	.55	.51	Post-Precambrian chert, quartzite, or other .58
	N-80	--	.53	.56	.57	Post-Precambrian chert, quartzite, or other .51
	N-82	--	.42	.55	.46	Post-Precambrian chert, quartzite, or other .47
	N-84	--	.56	.45	.49	Post-Precambrian chert, quartzite, or other .50

Bow Valley - continued

TABLE VIII - continued

Till	Sample Number	Precambrian Shale (Argillite)	Lower Cambrian Quartzitic Sandstone	Dolomite (mostly Paleozoic)	Limestone (mostly Paleozoic)	Other
Bow Valley - continued	N-86		.40	.51	.46	Post-Precambrian chert, quartzite, or other .49
	N-89	.50	.48	.46	.47	Post-Precambrian chert, quartzite, or other .46
	N-91	--	--	.32	.37	Post-Precambrian chert, quartzite, or other .40
	N-93	--	.53	.46	.50	Post-Precambrian chert, quartzite, or other Shale .55 .30
	N-117	--	.50	.52	.49	Post-Precambrian chert, quartzite, or other Shale .49 .50
	N-122	--	.53	.48	.57	Post-Precambrian chert, quartzite, or other .52
	N-123	--	.52	.51	.48	Post-Precambrian chert, quartzite, or other .44
	N-133	--	.50	.40	.41	Post-Precambrian chert, quartzite, or other Shale .37 .33

TABLE VIII - continued

Sample Till Number	Precambrian Shale (Argillite)	Lower Cambrian Quartzitic Sandstone	Dolomite (mostly Paleozoic)	Limestone (mostly Paleozoic)	Other
N-135	--	.47	.48	.46	Post-Precambrian chert, quartzite, or other Shale .43 .20
N-143	--	.32	.41	.44	Post-Precambrian chert, quartzite, or other Sandstone .37 Precambrian pebble congl. .30 .30
N-148	--	.40	.45	.44	Post-Precambrian chert, quartzite, or other Shale .33 .25
N-111	--	.50	.43	.40	Post-Precambrian chert, quartzite, or other .48
N-113	--	.44	.42	.50	Post-Precambrian chert, quartzite, or other .40
N-107	--	.50	.55	.52	Post-Precambrian chert, quartzite, or other .49

Bow Valley - continued

Till B

Till A

* See Table X for number of pebbles measured for average roundness of certain lithology, excluding broken pebbles, which seldom exceed 10% of the total.

** .1 - .2 - angular
.5 - .6 - subrounded
.9 - 1.0 - well rounded
.3 - .4 - subangular
.7 - .8 - rounded

TABLE X

Pebble count results (in percentage, 100 pebbles used in each sample).

Sample Number	Precambrian Shale (Argillite)	Lower Cambrian Quartzitic Sandstone	Dolomite (mostly Paleozoic)	Limestone (mostly Paleozoic)	Other
N-26	2*	94	1	2	Precambrian pebble congl. 1
N-31	7	41	25(1)**	24(1)	Precambrian pebble congl. 2 Siltstone 1
N-33	25(6)	25	36(4)	13	Precambrian pebble congl. 1
N-38	31(6)	50	10	7(2)	Post-Precambrian chert, quartzite, or other 2
N-40	11(2)	29	25(1)	34	Post-Precambrian chert quartzite, or other 1
N-42	15(3)	36	20	22(6)	Post-Precambrian chert, quartzite, or other 7
N-44	2(1)	45	21(1)	7	Post-Precambrian chert, quartzite, or other 21(1) Shale 4
N-158	6	20	34(2)	8	Post-Precambrian chert, quartzite, or other 30 Phyllite 2

Eisenhower Junction

TABLE X - continued

Sample Number	Precambrian Shale (Argillite)	Lower Cambrian Quartzitic Sandstone	Dolomite (mostly Paleozoic)	Limestone (mainly Paleozoic)	Other	
N-47	--	29	27	33	Precambrian pebble congl. Post-Precambrian chert, quartzite or other	3 8
N-49	--	8	42(4)	42	Post-Precambrian chert, quartzite or other	8
N-51	1(1)	4	26(4)	49(7)	Post-Precambrian chert, quartzite, or other Shale Precambrian pebble congl.	12 7 1
N-53	--	19	34(2)	31(6)	Post-Precambrian chert, quartzite, or other	16
N-57	--	11	39(7)	31(6)	Post-Precambrian chert, quartzite, or other	19
N-59	--	19	39	34	Post-Precambrian chert, quartzite, or other	8
N-73	--	15	33(4)	40(4)	Post-Precambrian chert, quartzite, or other	12
N-78	1	14	40(8)	18(4)	Post-Precambrian chert, quartzite, or other	27
N-80	--	9	41(7)	33(11)	Post-Precambrian chert, quartzite, or other	17

Bow Valley

TABLE X - continued

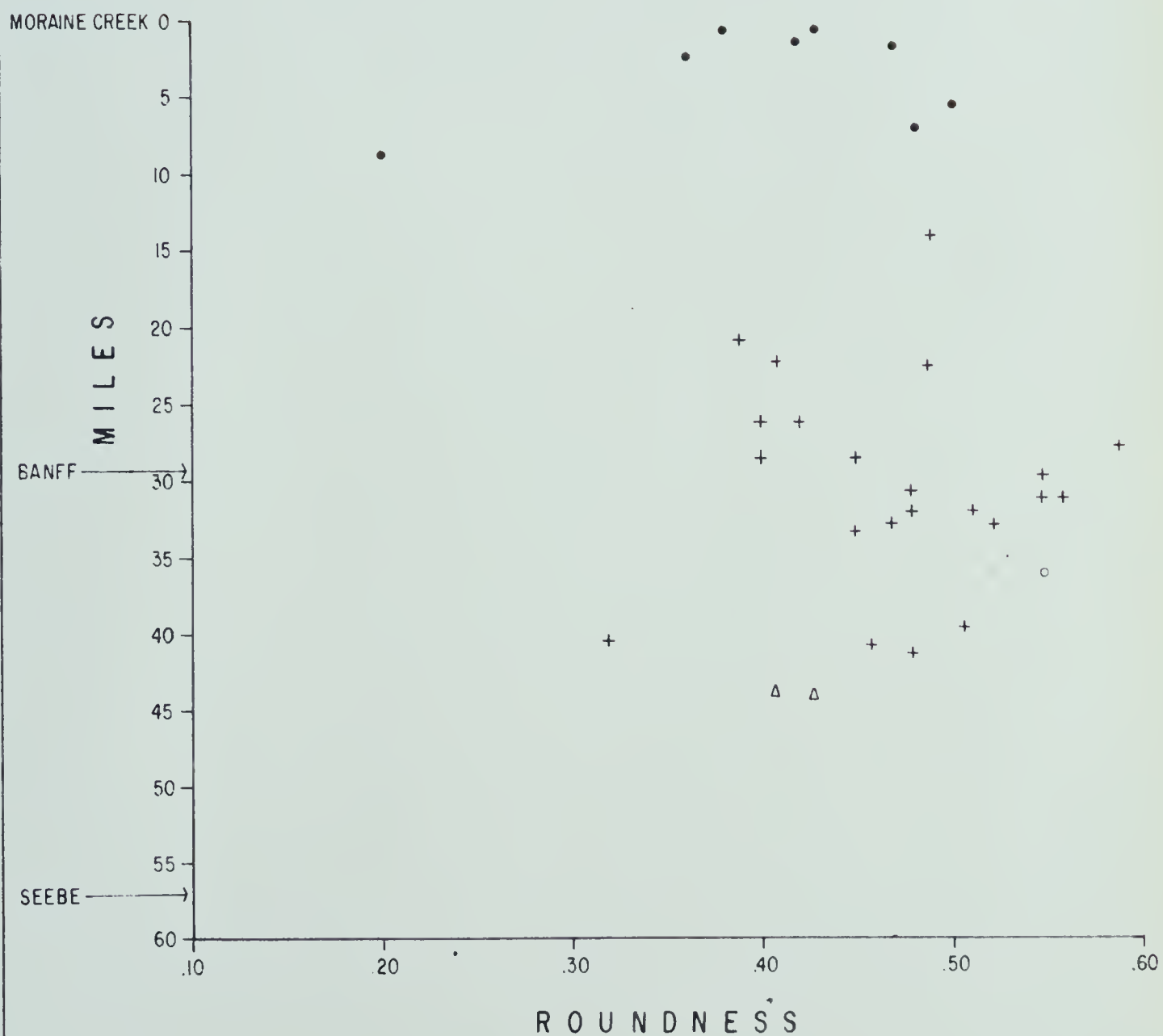
Till	Sample Number	Precambrian Shale (Argillite)	Lower Cambrian Quartzitic Sandstone	Dolomite (mostly Paleozoic)	Limestone (mostly Paleozoic)	Other
Bow Valley - continued	N-82	--	19	11(1)	56(4)	Post-Precambrian chert, quartzite, or other
	N-84	--	17	40(4)	25	Post-Precambrian chert, quartzite, or other
	N-86	--	12	19(5)	58(3)	Post-Precambrian chert quartzite, or other
	N-89	1	8	32(4)	51(1)	Post-Precambrian chert quartzite, or other
	N-91	--	--	10	84(3)	Post-Precambrian chert quartzite, or other
	N-93	--	12	31(3)	44(3)	Post-Precambrian chert, quartzite, or other Shale
	N-117	--	13	21(7)	38(13)	Post-Precambrian chert, quartzite, or other Shale
	N-122	--	14	28(4)	40(3)	Post-Precambrian chert, quartzite, or other
	N-123	--	5	35(1)	49(3)	Post-Precambrian chert, quartzite, or other

TABLE X - continued

Till	Sample Number	Precambrian Shale (Argillite)	Lower Cambrian Quartzitic Sandstone	Dolomite (mostly Paleozoic)	Limestone (mostly Paleozoic)	Other
Bow Valley - continued	N-133	--	3	34	40(2)	Post-Precambrian chert, quartzite, or other Shale 20 3
	N-135	--	17	31(2)	28(2)	Post-Precambrian chert, quartzite, or other Shale 23 1
	N-143	--	18	40(2)	19(4)	Post-Precambrian chert, quartzite, or other Sandstone 20 2 1 Precambrian pebble congl.
	N-148	--	1	31(1)	46(5)	Post-Precambrian chert, quartzite, or other Shale 20 2
Till B	N-111	--	4	27(7)	55(17)	Post-Precambrian chert, quartzite, or other 14
	N-113	--	13	28	42(7)	Post-Precambrian chert, quartzite, or other 17
Till A	N-107	--	5	36(9)	44(8)	Post-Precambrian chert, quartzite, or other 15

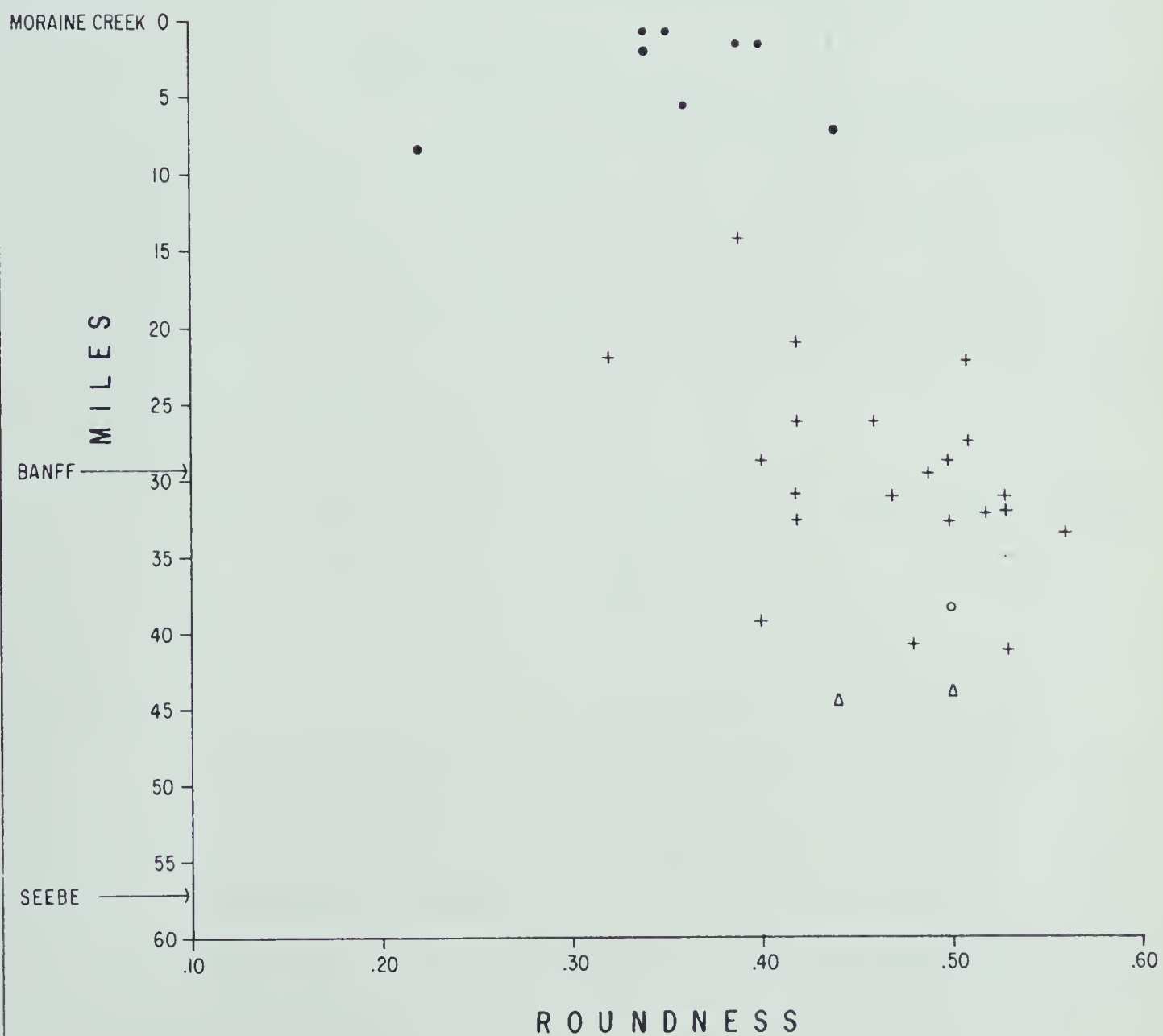
* Also records number of pebbles used in calculating average roundness (Table VIII).

** Parentheses indicate number of pebbles with striations.



● EISENHOWER JUNCTION TILL, + BOW VALLEY TILL, Δ TILL B, ○ TILL A

Figure 18. Average roundness of dolomite pebbles (4 to 64 mm) of various till samples plotted against position in the Bow River valley. (See Table X for number of pebbles considered.)



● EISENHOWER JUNCTION TILL, + BOW VALLEY TILL, Δ TILL B, ○ TILL A

Figure 19. Average roundness of Lower Cambrian quartzitic sandstone pebbles (4 to 64 mm) of various till samples plotted against position in the Bow River valley. (See Table X for number of pebbles considered.)

the quartzitic sandstone is located in the same areas as the Eisenhower Junction Till. The reason this roundness difference is not apparent in the dolomite may be due to the fact that dolomite reaches its roundness maturity relatively fast because of its lower resistance to abrasion and therefore differences in roundness between till pebbles could not be detected with the method employed.

Pebble Composition:

Method of Investigation: One hundred pebbles were randomly collected from till at each site. The pebbles vary generally between 4 and 64 mm. The writer's sampling technique was tested for bias by having each of four people (including the writer) collect a one hundred pebble sample at the same site (within 2 square feet). The Null hypothesis was set up that these four samples were not significantly different.

The Chi-squared Test, which was employed, is expressed by the formula:

$$\chi^2 = \sum \left[\frac{D^2}{E} \right]$$

where:

D = the corrected difference between the observed frequency and expected frequency.

E = expected frequency.

Table IX gives the observed frequency of the major categories of rocks collected in the four samples.

TABLE IX

Observed Frequency of Four Major Rock Types of Four Samples Collected at the Same Site by Four People

Rock Type	Sample X 1	Sample X 2	Sample X 3	Sample X 4	Total
Lower Cambrian quartzitic sandstone	10	9	9	8	36
Post-Precambrian quartzite, chert, or other	16	18	25	24	83
Limestone (principally Paleozoic)	45	45	38	39	167
Dolomite (principally Paleozoic)	29	28	28	29	114
Totals	100	100	100	100	400

χ^2 was calculated to be 3.39. This means that with nine degrees of freedom, P (probability) = .95. P was determined by using Yule and Kendall's table, "Significance points of χ^2 " (1950, p. 665). Therefore, at this probability level, there is no reason to suspect that the variations in the samples cannot be due to random sampling, and therefore the writer is unbiased in his selection of pebbles.

Van Der Plas and Tobin (1965, p. 88) have prepared a chart for judging the reliability of point counting results based on the standard deviation:

$$\zeta = \sqrt{\frac{p(100 - p)}{n}}$$

with 95% confidence (2ζ) where:

p = the real content of a mineral in percent by volume

n = the total number of points counted.

When adapting the chart for use here, the writer noted that for a certain variety of rock making up between 5% and 95% of one hundred pebbles, the 2ζ falls between about 4% and 10%. If two hundred pebbles had been counted, the reliability would have increased only slightly more than 2%. For the present study, one hundred

pebble samples are satisfactory.

Results: The rocks were grouped by major lithologies, which correspond to a certain geological age. Table X and Figure 20 present the results of pebble counts. Dolomite and limestone are the most important constituents in all till varieties except the Eisenhower Junction Till. Both rock types are essentially Paleozoic in age, and both are represented by a wide selection of varieties, which, however, were not differentiated. (See descriptions of rock-types in Chapter 3).

Lower Cambrian quartzitic sandstone pebbles are numerically the most important constituents of the Eisenhower Junction Till. They are easily identifiable because of their distinctive colors, usually white or pink with minor numbers of grays, brown, and purples. Precambrian shale (argillite) pebbles, usually greenish or reddish, occur frequently in the Eisenhower Junction Till, but seldom or never in the other varieties.

In the category "post-Precambrian chert, quartzite, and other," the "other" covers a variety of materials difficult to identify, but most are weathered sandstone, siltstone, or shale. Also, occasional Precambrian pebble conglomerate, siltstone, and shale are found.

The important fact brought out by this analysis is that all the rocks identified could have been derived from the bedrock in the Main and Front Ranges area. Therefore, there is no reason to suspect from the data presented here that the ice which carried the pebbles originated in a different bedrock terrain than that of the Main and Front Ranges.

The plot of the ratios of rocks derived principally northwest of Eisenhower Junction (Precambrian shale plus Lower Cambrian sandstone) to post-Lower Cambrian rocks (derived from all through the Bow River valley) reveals no gradual decrease in the relative amount of the former downvalley, but rather an abrupt break

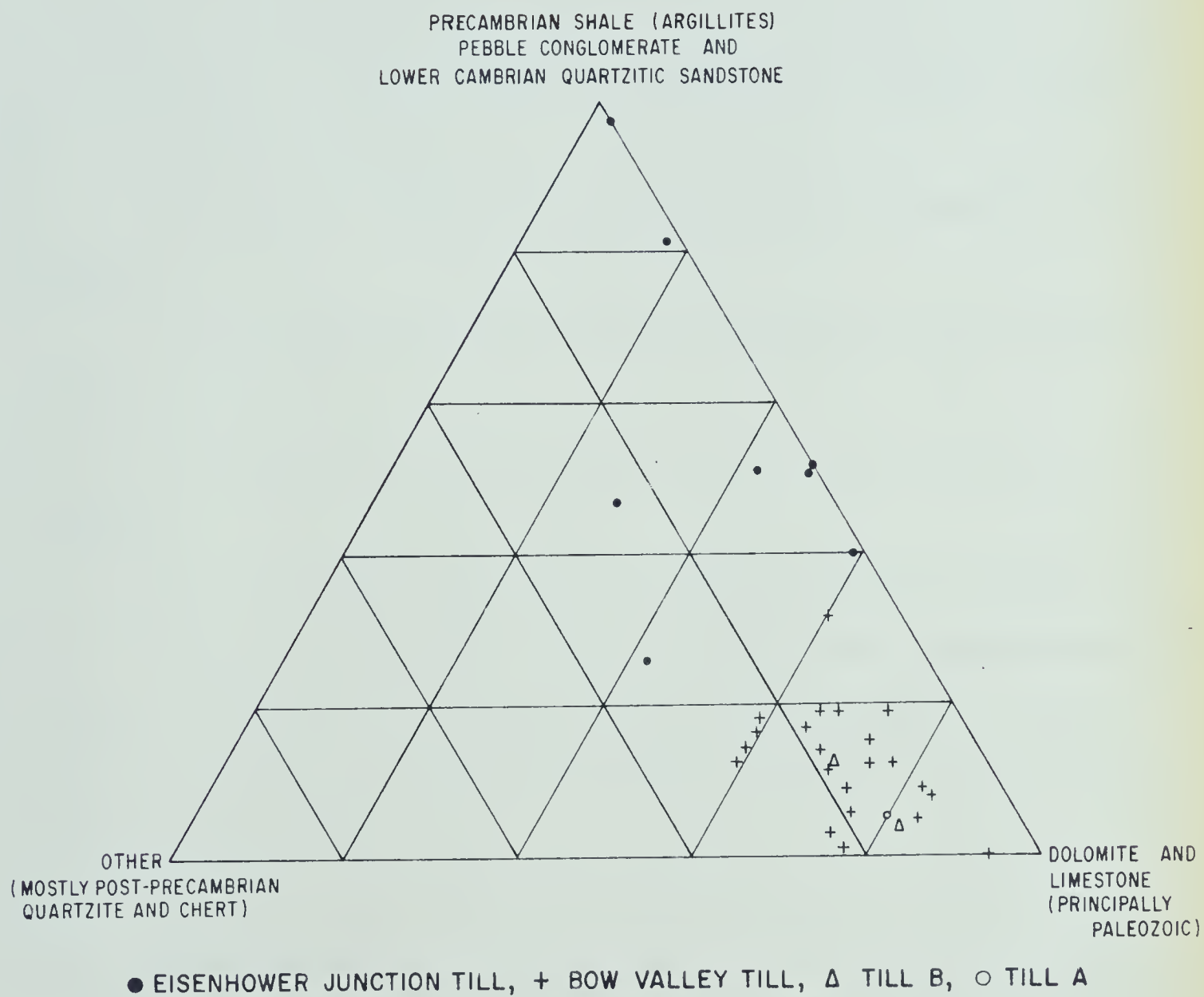


Figure 20. Pebble composition of tills in the Banff area.

between till types occurring at a location where the bedrock changes grossly (Table XI; Figure 21). Regardless of the fact that the tills belong to different stratigraphic units, the ice that deposited them originated in the same areas and therefore a gradual decrease in the number of specimens of a certain rock-type away from the source would be expected. Failure for this to occur could be due to a number of factors, the more important ones being:

1. Too short a distance of transport is involved for the decrease to be detected.
2. Large quantities of local material were added to the ice during deglaciation.
3. The gradation is narrow and does not show up in the scale used in Figure 21.
4. An insufficient number of samples were analysed in the transition zone.

Table X shows the number of striations found on pebbles counted in each rock category. Striations are most common on the dolomite and limestone, having been observed on as many as one-third of the pebbles in one sample. Generally, however, this figure is much lower.

Observation of the bedrock map of the area (Map 4) reveals that Mesozoic shale, siltstone, and sandstone are present or believed to be present in large areas of the Bow River valley floor. These rock-types are rare in the gravel-sized fraction of the till, because of their inherent low resistance to mechanical disintegration.

Heavy Minerals :

Method of Investigation: Heavy minerals were separated with Bromoform (2.890 s.g.), employing standard procedures, from the less than 2.0 mm. and greater than .074 mm. size fraction of selected till samples. The carbonates and iron oxide were removed beforehand with concentrated HCl. The heavies finer than .177 mm. (80 mesh) were mounted on glass slides with Aroclor ($n = 1.66$ to 1.67).

TABLE XI

Ratio of Precambrian rocks plus Lower Cambrian Sandstone to Post-Lower Cambrian rocks.

Sample Number	Precambrian + L.C Ss Post-Lower Cambrian	Sample Number	Precambrian + L.C Ss Post-Lower Cambrian
N-26	32.33	N-84	.20
N-31	1.00	N-86	.13
N-33	1.04	N-89	.09
N-38	4.26	N-91	.00
N-40	.66	N-93	.14
N-42	1.04	N-117	.14
N-44	.88	N-122	.14
N-158	.36	N-123	.05
N-47	.47	N-133	.03
N-49	.08	N-135	.20
N-51	.06	N-143	.23
N-53	.23	N-148	.01
N-57	.12	N-111	.04
N-59	.23	N-113	.15
N-73	.18	N-107	.05
N-78	.18		
N-80	.09		
N-82	.23		

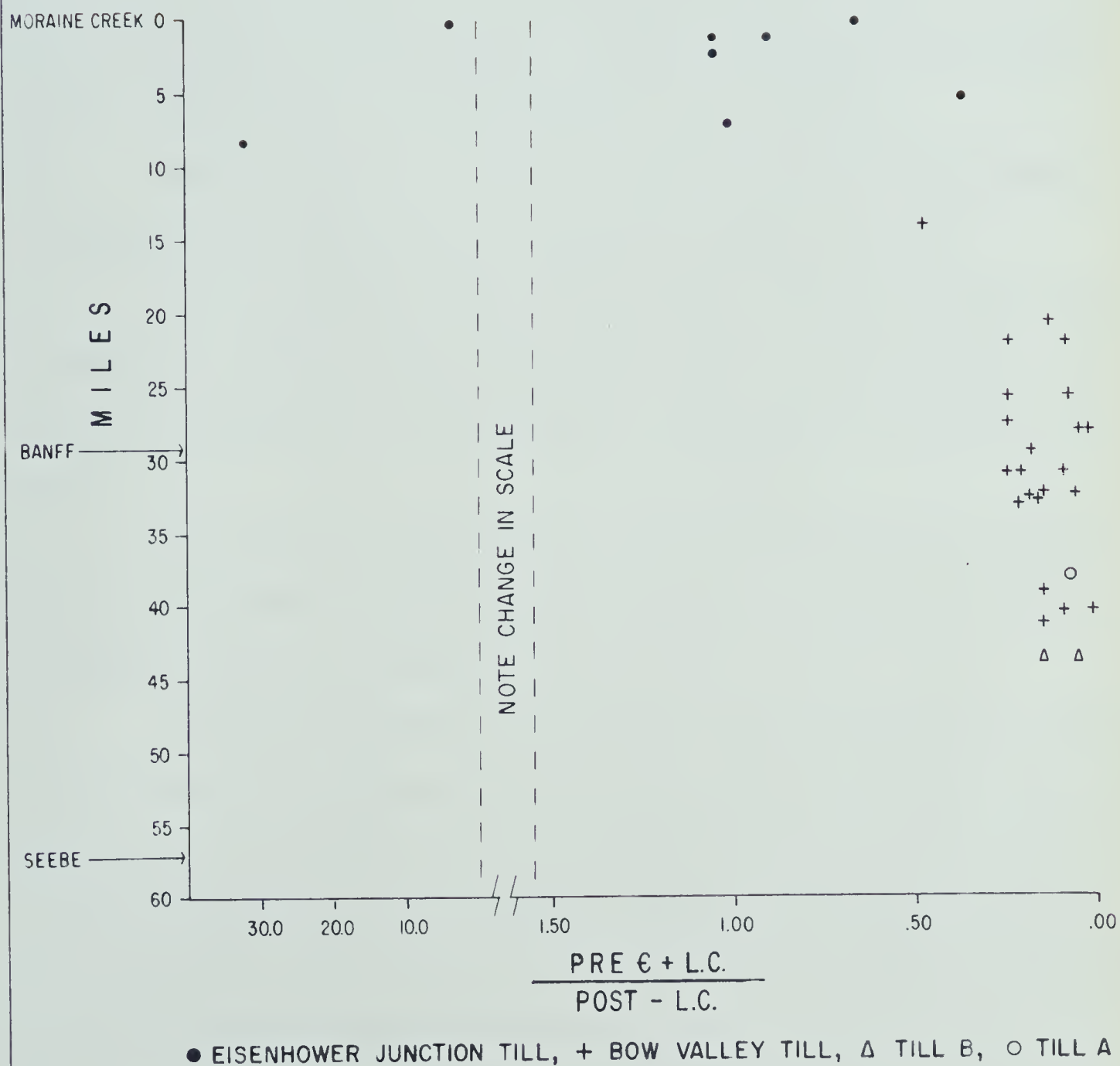


Figure 21. Ratio of Precambrian rocks plus Lower Cambrian sandstone to post-Lower Cambrian rocks in various till samples, plotted against position in the Bow River valley.

At least one hundred and fifty non-opaque grains (or the total number available if less than that) were counted on each slide. Unidentified minerals, which never exceeded 3%, are excluded from the table.

Results: Table XII shows the percentage of each variety of heavy mineral counted. The total percentage of heavy minerals in the .074 mm. to 2.0 mm. grain size range of the till, including the carbonates, never exceeds 0.5%. Opaque minerals, although abundant, were not studied.

Apatite is present, but was not counted because most of it was probably destroyed during the treatment of the samples with concentrated HCl.

Zircon is the most abundant mineral found. The grains are often rounded, although fresh-looking prismatic grains terminated with pyramids commonly occur (Plate X). Overgrowths, some rounded, as well as inclusions and zoning are present.

Tourmaline is extremely common, with several species observed, but few good striated prismatic crystals are present; most grains are angular to subangular fragments, some having overgrowths and inclusions.

Chlorite and hypersthene are second and third in abundance. The chlorite, usually tabular with a hexagonal outline, includes grains which are principally subangular to subrounded. Goodeuhedral and subangular grains of hypersthene are common, often occurring as single prisms, although clusters of crystals are found. The pleochroism, from a pale green to a pale brownish pink, is distinct. Glass shards protrude from the surfaces of most crystals.

The remainder of the heavy minerals observed, occurring in various degrees of rounding and crystal development, show nothing extraordinary.

The three important results of the heavy minerals analysis are:

1. Heavy minerals are of no value in correlating or distinguishing tills in the Banff area.
2. The presence of hypersthene with glass shards (also some of the well

TABLE XII - continued

Eisenhower Junction (continued)	N-45	43	7	11	6	13	9	-	-	-	-	-	9	-	2	-	-	-	-	54
	N-159	43	4	5	11	6	25	2	3	-	-	-	-	-	-	-	tr	tr	-	186
Bow Valley	N-48	19	10	8	8	3	7	-	31	8	-	3	-	tr	1	1	tr	-	-	195
	N-50	38	21	5	11	6	3	-	7	6	tr	2	-	-	-	-	-	tr	-	105
	N-60	46	10	1	18	8	4	-	-	3	1	-	-	1	8	-	-	-	-	78
	N-69	60	15	10	5	-	-	-	-	5	-	-	-	-	5	-	-	-	-	20
	N-79	44	22	10	16	3	-	1	-	2	-	-	-	1	-	-	-	1	-	152
	N-83	43	23	11	7	5	2	1	tr	4	-	tr	tr	-	2	tr	-	-	tr	190
	N-85	29	22	8	9	2	13	-	2	4	-	tr	1	tr	9	-	-	-	-	137
	N-87	21	14	7	10	12	13	1	9	3	2	1	tr?	1	3	1	-	tr	-	162
	N-92	17	-	-	50	-	33	-	-	-	-	-	-	-	-	-	-	-	-	6
	N-94	36	26	7	13	tr	8	tr	5	-	tr	-	-	1	tr	tr	-	-	-	136
	N-118	-	25	50	-	-	25	-	-	-	-	-	-	-	-	-	-	-	-	4
	N-120	37	13	3	7	5	7	4	-	tr	2	-	-	-	21	-	tr	-	-	191
	N-124	34	32	10	16	-	3	-	tr	4	-	-	tr	-	-	-	-	-	-	134
	N-136	44	14	19	13	-	3	-	-	-	-	-	-	1	3	3	-	-	-	70
	N-147	33	23	2	33	2	-	-	5	-	-	-	2	-	-	-	-	-	-	33
	N-149	20	4	4	16	12	8	-	20	12	-	-	-	4	-	-	-	-	-	25
Till A	N-106	38	21	9	6	6	4	-	6	2	-	-	4?	-	2	-	-	-	-	53

* Tourmaline variations:

Tourmaline I - various shades of green; if pleochroism observed, green-black; or green-blue

Tourmaline II - various shades of brown to black; if pleochroism observed brown-black

Tourmaline III - blue; if pleochroism observed, blue-pink, blue-black, or blue-brown

Tourmaline IV - greenish brown; if pleochroism observed, green-brown.

** tr = less than 1%

formed augite) suggests a volcanic ash origin. Although heavy mineral analyses are scarce, hypersthene is rarely reported from bedrock found in the Main and Front Ranges of the Canadian Rocky Mountains or equivalent rocks in the subsurface. Kirmani (1962, p. 31) observed a small amount in the insoluble residues of the Duhamel Reef of central Alberta. The Pleistocene volcanic ash layers reported in western Canada, particularly the Mt. Mazama and Glacier Peak, (Powers and Wilcox 1964, p. 1,334) are not predominantly hypersthene types. Therefore, this hypersthene, which may be derived from an unreported volcanic ash may in the future help decipher the glacial stratigraphy of western Canada. However, glass shards and well formed crystals do not prove that the material is derived from a Pleistocene volcanic ash layer. The samples with the greatest concentration of hypersthene are located in the same general area, which is the northwest part of the study area (Map 6, Table XII). Another fact that cannot be overlooked is the great amount of hypersthene with glass shards relative to the total heavy mineral suite. A major source of ash would be needed to make the hypersthene so prominent.

3. There is no reason to doubt that all of the heavy minerals found, with the exception of hypersthene and perhaps some augite, were derived from the bedrock that crops out in the Main and Front Ranges of the Canadian Rocky Mountains. This premise is partly supported by the great abundance of zircon and tourmaline found in the samples analysed. These two minerals are also abundant in the Spray River Formation in Banff National Park (Shafiuddin 1960, p. 23) and the Jasper Formation (Akehurst 1964, p. 28). The latter formation has equivalents of similar lithology in Banff National Park. Also, no suite of minerals was found such as a metamorphic series, that would be difficult to explain as being derived from this area.

Light Minerals:

Method of Investigation: The light mineral fraction of several samples (minus carbonates) was mounted with Aroclor ($n = 1.66$ to 1.67) and

investigated.

Results: The light fraction consists mainly of angular to subangular quartz. Chert and dark rock fragments are also present in minor amounts.

Clay Mineralogy (X-ray):

Method of Investigation: The clay mineral varieties and their relative amounts were determined for the less than 2.0 mm. size fraction of selected till samples. Carbonate-free samples were powdered and mounted in cellulose tablets at 30,000 psi in order to orient the particles. All samples were run untreated through a Philips water cooled X-ray diffraction unit (type no. 12045, 60 cycle, University of Alberta). Since the patterns were essentially the same except for the intensities, six were selected for further analyses to pinpoint the clay minerals present. These results were then extended to the other samples.

Results: Figure 22, 23, and 24 present the results for untreated, glycolated, and heated samples of six selected samples (N-20, N-34, N-39, N-45, Eisenhower Junction Till; N-48, N-147, Bow Valley Till). Table XIII shows typical spacings of the common clay minerals (modified after Weaver 1958).

TABLE XIII

Selected X-Ray Diffraction Spacings of Common Clay Minerals

Clay	001	002	003	004	005
Micaceous Mineral	10Å	5Å	3.3Å	2.5Å	2Å
Montmorillonite	12-15Å	6-7.5Å	4-5Å	3-3.7Å	2.4-3Å
Chlorite	14Å	7Å	4.7Å	3.53Å	2.8Å
Kaolinite	7Å	3.57Å	2.3Å	1.8Å	1.4Å

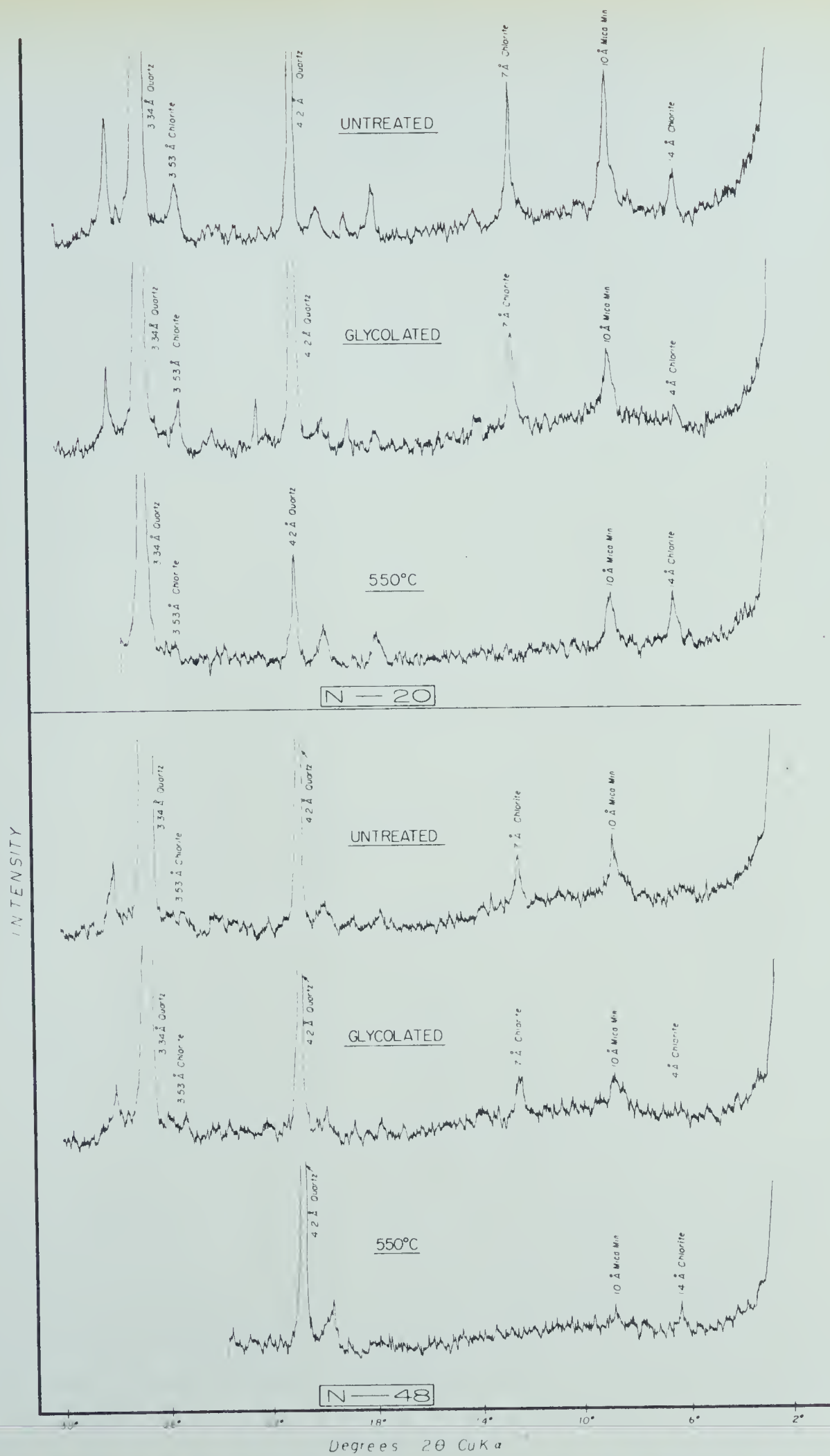


Figure 22. X-ray diffraction patterns of till samples N-20 (Eisenhower Junction Till) and N-48 (Bow Valley Till).

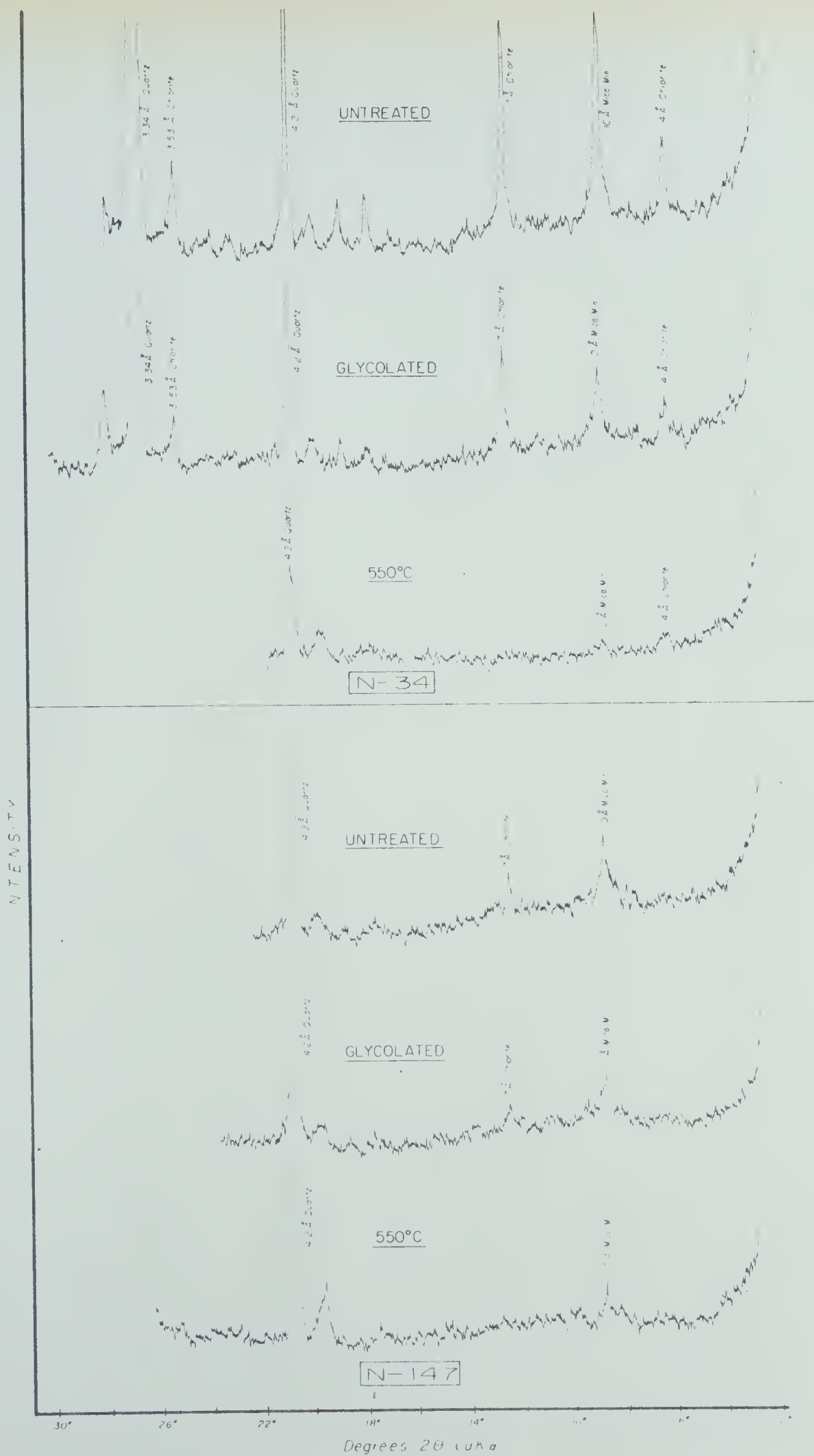


Figure 23. X-ray diffraction patterns of till samples N-34 (Eisenhower Junction Till) and N-147 (Bow Valley Till).

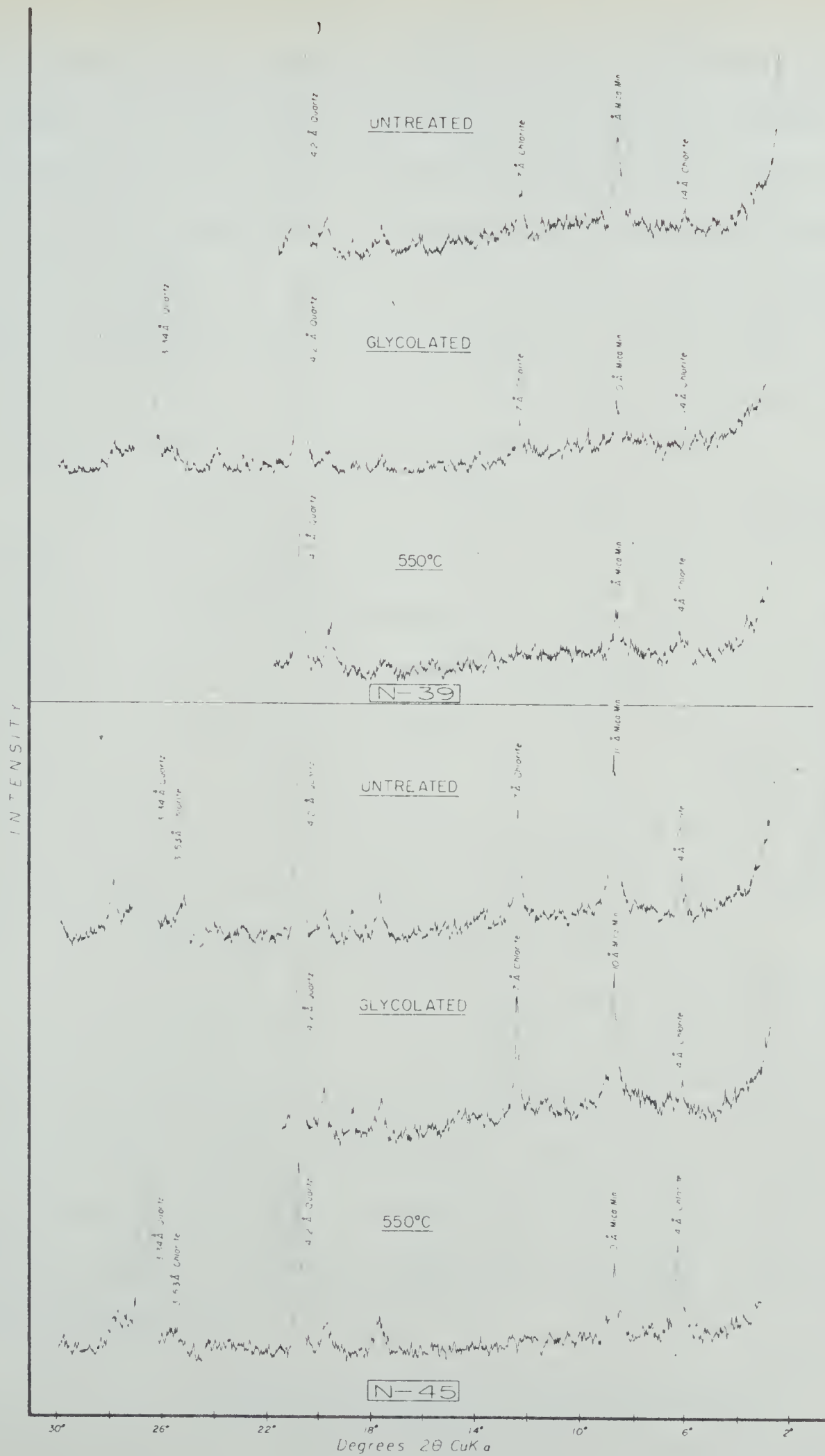


Figure 24. X-ray diffraction patterns of till samples N-39 and N-45 (Eisenhower Junction Till).

In all six untreated samples 14Å, 10Å, and 7Å spacings were present, except in N-48 and N-147, which showed no 14Å peak. It is likely that the 10Å spacing represents the 001 layer of a micaceous mineral. When treated with glycol, the 14Å spacing did not expand to 17Å, indicating montmorillonite is not present, at least in any identifiable amount. Smear samples were prepared on glass slides and heated to 550° C for more than 2 hours. The 14Å spacings increased in intensity, indicating chlorite, and the 7Å (either 001 of kaolinite or 002 of chlorite) spacing was destroyed. The fact that the 14Å spacing did not collapse to 10Å eliminated the possibility of vermiculite being present in quantity.

Thus it appears that chlorite is definitely present, with the possibility of kaolinite. The writer thinks, however, that certain evidence rules out kaolinite. Kaolinite has a strong 002 peak at about 3.57 Å, while chlorite has an intense 004 peak at 3.53 Å. In the patterns under discussion, a peak invariably occurs at about 3.53 Å, but there is nothing distinct at 3.57 Å. Therefore, chlorite without kaolinite is indicated. Chlorite, along with a micaceous mineral, are the only two minerals of any quantitative importance detected here. Because it was not detected in the heavy mineral analysis, the micaceous mineral is not biotite. Also, there is no evidence in the patterns for abundant mixed layering.

According to Dr. S. Pawluk, Soils Department, University of Alberta, (personal communication) when the intensity of the 7Å (002) chlorite peak is twice that of the 10Å (001) peak of micaceous minerals, these clay varieties are present in roughly equal amounts. Using this criterion, the relative amounts of the micaceous mineral and chlorite were determined. In all cases except one, there is more micaceous mineral than chlorite; in sample N-79, there appears to be approximately equal amounts of both.

Clay Mineralogy (Differential Thermal Analysis) :

Method of Investigation: It was demonstrated that a mic-

aceous mineral and chlorite are the dominant clay minerals present in the till samples analysed. For more exact description, the variety of the micaceous mineral was determined by differential thermal analysis techniques. Differential Thermal Analysis model 4-4442, using a Loddington-Hammel Furnace, No. 168-61130 and Hewlett-Packard model 135AX-Y Recorder of the Soils Department, University of Alberta, was employed. The less than 2.0 mm. size fraction minus carbonates was ground to a fine powder for the analysis.

Results: The micaceous mineral can only be muscovite or "illite" (used here to include any mica-like clay mineral). Figure 25 shows the results of analyses of six typical samples (N-20, N-34, N-39, N-45, Eisenhower Junction Till; N-48, N-147, Bow Valley Till). Most patterns show a weak endothermic peak at about 100°C (H_2O reaction), and all show a broad endothermic curve with a peak at 555° C (dehydroxylation reaction). The patterns suggest that "illite" and chlorite are present. It was determined previously from the X-ray diffraction work that chlorite is present. The conclusion that "illite" is present and not muscovite is based on curve characteristics that are usually present for "illite" in an O_2 atmosphere, even though the curves of muscovite and "illite" may vary widely according to chemistry, crystallinity, and grain size. If the second endothermic peak of muscovite occurs, it is at about 750° C or higher (Mackenzie 1957, p. 181). In illites the main endothermic peak may occur between 550 and 720° C (Mackenzie 1957, p. 183). Interpreting the patterns of Mackenzie (1957, p. 212) for chlorite, this same peak generally varies between about 625 and 700° C. Finely ground material may lower the equivalent peak temperature by 50° C in chlorite (Mackenzie 1957, p. 213). Combining illite and chlorite, Mackenzie (1957, p. 269) says, "The differential thermal curves for these mixtures differ little from that for illite, although there are slight differences in the 500 and 700° C region." Brown (1961, p. 227) shows patterns for this combination with a relatively strong

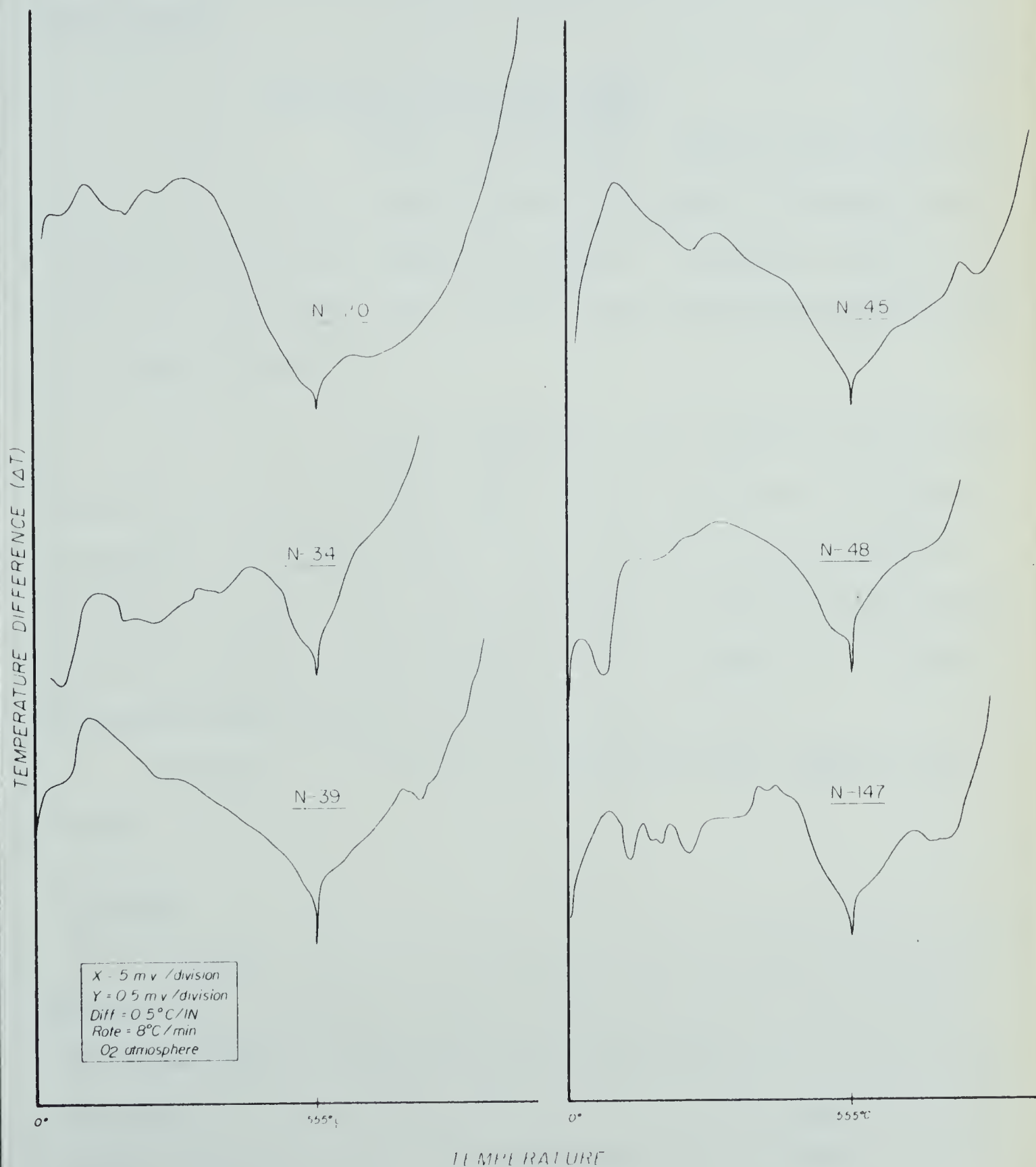


Figure 25. Differential thermal analysis patterns of six typical till samples (N-20, N-34, N-39, N-45, Eisenhower Junction Till; N-48, N-147, Bow Valley Till).

endothermic peak at about 570° C for one sample and about 590° C for another

Thus, clay mineral analyses has been useful for describing the tills of the Banff area further, but not for distinguishing till units, since all tills contain the same types of clay minerals.

Carbonate Content of Till Samples :

Method of Investigation: Quantitative gasometric determination of the calcite and dolomite content of the less than .074 fraction of the till samples was determined by using Chittick apparatus. The procedure followed is outlined by Dreimanis (1962). Known amounts of calcite and dolomite were used to test the equipment (Appendix B).

Results: Table XIV and Figure 26 give the results of the carbonate determination of certain samples. When the total amount of carbonates in the samples is plotted against position in the Bow River valley, the two major till varieties can be differentiated. There also appears to be a slight increase in carbonate content downvalley within the Bow Valley Till. The composition of the underlying and surrounding bedrock is responsible for these phenomena.

Individual till units cannot be differentiated by types or amounts of carbonates.

Conclusion

An attempt was made to distinguish the relative importance of ablation and lodgement till. The results of laboratory analyses, coupled with field observations and the physiography throw little light on the relative abundance of these till types. Nevertheless it may be stated that areas where linear erosional ridges are found are probably underlain by lodgment till, whereas areas that support dead-ice features (besides outwash) contain ablation till.

TABLE XIV

Percentage of Carbonate in less than .074 mm. size fraction of till

Till	Sample Number	% Dolomite	% Calcite	% Total Carbonates
Eisenhower Junction	N-20	17.8	23.2	41.0
	N-27	12.5	14.0	26.5
	N-32	18.0	17.0	35.0
	N-34	12.5	17.2	29.7
	N-39	10.3	24.8	35.1
	N-41	23.1	24.2	47.3
	N-45	9.0	19.6	28.6
	N-159	16.8	19.5	36.3
Bow Valley	N-48	24.6	20.8	45.4
	N-50	39.3	22.0	61.3
	N-60	34.6	26.1	60.7
	N-69	37.9	41.5	79.4
	N-79	37.0	33.0	70.0
	N-83	28.5	29.0	57.5
	N-85	39.5	23.2	62.7
	N-87	26.6	35.0	61.6
	N-92	41.0	43.2	84.2
	N-94	42.6	24.5	67.1
	N-118	31.7	35.6	67.3
	N-120	35.5	30.0	65.5
	N-124	34.0	23.5	57.5
	N-136	35.2	39.5	74.7
	N-147	26.8	29.0	55.8
	N-149	10.4	28.0	38.4
Till A	N-106	27.8	33.2	61.0

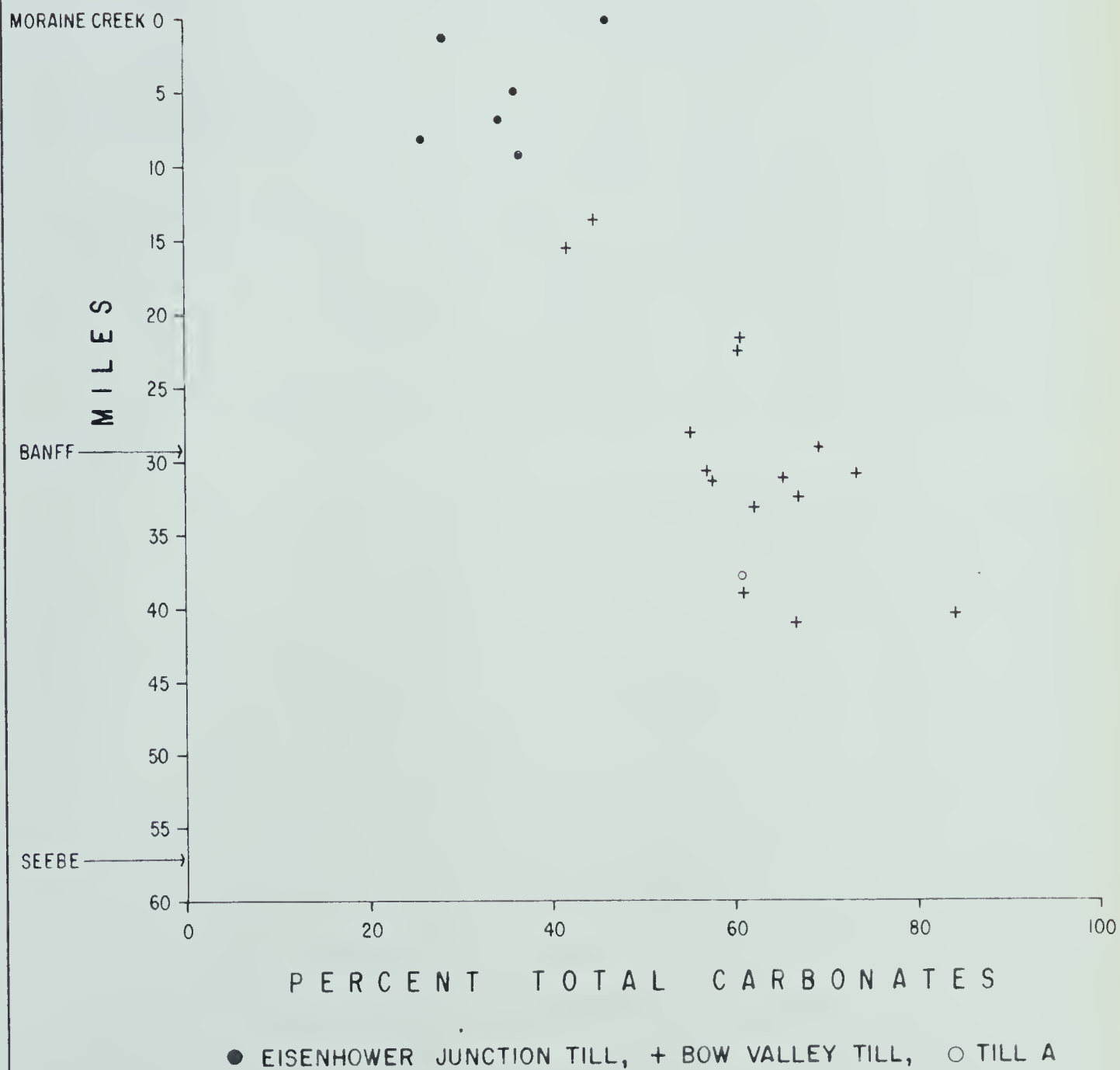


Figure 26. Percentage of total carbonate content in various tills in the less than .074 mm size fraction, plotted against position in the Bow River valley.

Glacio-Fluvial Deposits

General Statement

Extensive glacio-fluvial deposits are present in the Banff area. These can be subdivided into major groups based on morphology, origin, and complexity (Maps 1, 2, and 3).

Ice-Contact Fluvial Deposits

Ice-contact fluvial deposits forming recessional moraines are located about 4 miles east of Banff townsite, and about 1 1/2 miles northwest of Canmore (Map 2). In the former area, good outcrops are exposed along the steep bluff on the northeast side of Route 1. In the latter area, outcrops are less abundant, and non-ice-contact outwash may actually be present in much of the area mapped as ice-contact fluvial deposits.

In both areas, the deposits are laterally continuous with other glacial deposits. Near the Banff townsite area, ice-contact fluvial deposits grade into till to the northwest and outwash plain deposits to the southeast. Non-ice-contact outwash deposits are exposed both to the northwest and to the southeast of the ice-contact fluvial deposits, northwest and east of Canmore. Remnants of Tills A and B and other outwash units probably underlie the ice-contact outwash. These ice-contact fluvial deposits probably formed kames originally, but do not display the typical hummocky morphology of kame deposits today because a re-advance of the Bow Valley glacier has eroded and smoothed out the surfaces and deposited a thin discontinuous cover of till. Patches of loess and washed gravel sometimes overlie the ice-contact fluvial deposits. The thickness of the ice-contact outwash is at least 100 feet.

Ice-contact fluvial deposits are composed principally of gray, poorly to well sorted, unconsolidated gravels dipping steeply in a variety of directions, but mainly to the southeast. Minor amounts of sand, silt and clay are present. Pebble-sized material dominates, with various degrees of rounding. The rock-types of fragments

reflect the composition of the coarse fraction of the till in the same general area. Essentially all pebbles have lost any glacial striations which may have existed. Till lenses are present in the deposits in some locations.

Of minor importance are ice-contact fluvial deposits occurring near the southwest end of Lake Minnewanka (Map 2). In the Spray River valley outwash which may be ice-contact, representing a recessional moraine, is present.

Ice-Contact Fluvial Complex

Near Eisenhower Junction, there is a complex of glacial deposits and forms designated as an "ice-contact fluvial complex" (Map 1, Plate V). The morphology and general characteristics of this complex have been explained in Chapter 2 under Major Valleys physiographic unit. Ground moraine grades southeastward into this complex which consists in part of a series of side glacial stream channels and probably side glacial stream deposits. The lithology of the side glacial stream area could not be inspected. Farther downstream this series grades into ice-contact fluvial deposits which represent another part of this complex and the terminal moraine of the Eisenhower Junction advance. Outcrops of this moraine are present along Route 93 west of Eisenhower Junction, with a particularly good outcrop located in a gravel pit about a mile southwest of Eisenhower Junction on the south side of Route 93 (Plate XI). Although the lower contact of the outwash is not seen in most exposures, the deposits lie directly on bedrock in some areas. This can be observed southeast of Route 93, toward the limit of the unit, where the sediments gradually thin out. The upper surface of the complex is exposed in most cases, having been "smoothed over" by a re-advance which left intermittent patches and lenses of till. (This till was not mapped separately). The thickness of these outwash deposits varies considerably; the section exposed in the gravel pit mentioned above is typical and measures 43 feet, 4 inches.

The lithology of the unit varies from till to well sorted gravel with minor

sand, silt and clay. Where the unit thins to the southeast, the material is probably ablation till because the small grain size fraction is more sandy than the till described previously. The major portion of the sediments of this unit resemble those exposed in the gravel pit. They are grayish, poorly sorted to moderately sorted unconsolidated gravels consisting of subangular to angular pebble-sized material, mainly limestone, dolomite, and quartzitic sandstone. Large sand and silt lenses comprise about 50% of the outcrop. The overall direction of dip of the strata exposed in the outcrop is $S35^{\circ}E+5-10^{\circ}$, with many variations. The gravel pit section is presented in Appendix A, Section 2.

Kame Moraine

From the point at which the Bow River enters the Foothills to the end of the area of investigation, a kame moraine is present, which consists of kames, eskers, and crevasse fillings (?) blanketing the surface and surrounded by non-ice-contact outwash (Map 3; Plate XII). No till has been found in any of the deposits.

The kame moraine is underlain by truncated bedrock. The thin non-ice-contact outwash deposits which surround the kames, eskers, and crevasse fillings(?) sometimes occur in low terraces. In the shale pit near Kananaskis Falls, and along the Kananaskis River, the outwash is about 6 feet thick (Plate IX C). The local relief of the ice-contact fluvial features varies, with representative sections measuring 24 feet, 1 inch and 11 feet, 4 inches.

The lithology of the kames, eskers, and crevasse fillings (?) is similar to that of the other ice-contact fluvial deposits described in the last two sections, consisting of grayish, unconsolidated, poorly to moderately well sorted gravels dipping steeply in a variety of directions (Plate XII A). Minor amounts of sand, silt and clay are present. Not uncommonly the bedding planes are truncated between successive layers. Limestone and dolomite pebbles in various degrees of roundness comprise most of the deposits. Sections considered typical are described in Appendix A, Sections

3 and 4.

Bedrock knobs more than 100 feet high located in the same area are covered by a thin veneer of glacial drift which may be ice-contact fluvial deposits.

Non-Ice-Contact Outwash

Non-ice-contact outwash is widespread in the Bow River valley from the Banff townsite area downstream to about the Kananaskis River (Maps 2 and 3). Four distinct units can be separated according to time of deposition or relationships with other deposits. The first extends in a crescent shape from northeast of Banff townsite to the confluence of the Bow and Cascade Rivers. Good outcrops occur along the banks of these two rivers. The unit is overlain by thick deposits of Bow Valley Till, with the lower contact not exposed (Plate VIII).¹ The thickness is fairly uniform; a 70-foot section of the outwash was measured near Anthracite.

On the southwest side of the Bow River near Canmore, Bow Valley Till overlies outwash, which may be equivalent to the outwash unit mentioned above.

The second distinct unit, an almost continuous plain of outwash, is present on the northeast side of the Bow River from 4 miles east of Banff townsite to Gap Lake (Maps 2 and 3). It is interrupted by ice-contact fluvial deposits, cross-cutting creeks, and recent alluvial deposits. The sites of the best outcrops are along Route 1A, where the Bow River is incised into the outwash, and along the cross-cutting creek walls. The outwash usually forms the surface, but occasionally patches of till resulting from a re-advance, loess patches, lacustrine deposits, wind-blown sand and washed gravels overlie it. Underlying the unit or surrounded by it are remnants of Tills A and B. The northeast side of the outwash abutts against bedrock

¹The "Hoodooos," a tourist attraction consisting of resistant pillars of glacial drift located 2 miles east of Banff townsite, are composed of this outwash near the base with Bow Valley Till above.

covered by a thin veneer of till or supporting only occasional erratics. An outcrop near Carrot Creek measured 59 feet (Plate XIII), and another about 3 miles southeast of Canmore 98 feet, 11 inches (Plate XII B). The total thickness in the area of the last measured section however, is estimated to be much greater. Outwash belonging to this unit may also underlie materials mapped as Bow Valley Till, located between Johnson Lake and Carrot Creek (Map 2).

A third non-ice-contact outwash unit north of Route 1 toward Lake Minnewanka forms high bluffs along the Cascade River (Map 2). The outwash was derived either from the Cascade River valley or Lake Minnewanka valley. The unit is estimated to be over 100 feet thick. While its relationship with other outwash deposits is not clear, on the southeastern side it appears to grade into thin gravel deposits above and till below, whereas in other places it truncates bedrock covered with a moderately thin veneer of till or scattered erratics.

The last distinct unit of non-ice-contact outwash is in the area of the kame moraine which was described in the last section. Also, minor amounts of outwash were observed in terraces in the lower part of the U-shaped portion of Johnston Creek valley.

The lithology of all the outwash units is similar. Gravel-sized material is volumetrically the most important, but sand and minor amounts of silt and clay occur. Sand and silt lenses are quite common. The gravels have an overall grayish or grayish-brown appearance and consist mainly of unconsolidated, poorly to well sorted dolomite and limestone pebbles, usually subrounded to rounded. Strata dip gently downvalley, with cross-bedding common (Plate XIV A). Sorting is better downvalley, with an accompanying increase in the number of sand and silt lenses. Measured sections and field descriptions of key outcrops are given in Appendix A, Sections 1, 5, and 6.

Meltwater Channel Deposits

Meltwater channel deposits are indicated on Maps 1, 2, and 3. They consist

generally of gravel, sand, and minor silt and clay.

Glacio-Lacustrine Deposits

Important glacio-lacustrine deposits are located about 2 miles northeast of Banff townsite near the town dump, in the Spray River valley about a mile upstream from the confluence of the Bow River, and on the shores and bars of Lac des Arcs (Maps 2 and 3). At the first location brownish gray, calcareous, very thinly-bedded to thinly-laminated, well-sorted, medium grained sand is present. Minor amounts of other sand size fractions and silt and clay occur. Individual beds are about 15 mm. thick, with some very thin cross-bedding and cross-laminations. No gravel-sized material is present except near the contacts with other surficial deposits. These sands are overlying stratified gravels on the southeast and northeast sides of the unit, which in turn is underlain by Bow Valley Till, lying on bedrock in places (Figure 9). In one location the sand overlies outwash, occurring under the Bow Valley Till. Toward the west, the same deposit thickens, reaching over 40 feet near the Banff town dump. Farther west the deposit forms bluffs above the recent floodplain. The thickness and location of the deposit suggests that the former lake was in part glacially dammed with the damming taking place during the last deglaciation of the area. Patches of sand overlying outwash gravels north of the Cascade River may belong to this unit.

In the upper part of the unit south of the Cascade River, the lake deposits have been reworked by wind into dunes which contain buried soils and are now stabilized. A 3-inch volcanic ash layer occurs at various depths (maximum about 6 feet) below the surface (Plate XV A).

The lake deposits observed up the Spray River consist of buff colored, calcareous, fine-grained material of clayey silt texture. Pebbles, the result of ice rafting, are sometimes observed. The lake was probably an ice-marginal lake, since outwash is found downvalley and on the lower part of the valley walls, suggesting

damming during deglaciation.

Remnant lacustrine deposits overlain by aeolian sand are exposed on bluffs along the north shore of Lac des Arcs, as well as on bars and a "spit" within the lake (Plate XIV B). The lacustrine material is buff, calcareous, well-sorted, laminated to thinly-laminated silty sand, with occasional ripple marks, gastropods, wood fragments and clay-sized material occurring. Just south of Exshaw the entire unit is about 50 feet above the water level of the Bow River.

In the past, Lac des Arcs was deeper than today. Most of the lacustrine material was deposited as a delta, probably during deglaciation following the Bow Valley re-advance. Since that time, the water level has lowered (see next chapter), the wind has reworked some of the material, and the Bow River has eroded much of the lacustrine material away. Wind is still shifting some of the sand today, but the greatest activity took place during deglaciation and during the Altithermal (see next chapter) when vegetation was minimal.

Aeolian Deposits

Loess

No widespread sheets of loess occur in the area under investigation. Restricted patches, most of which are too small to be shown on the map scale used, are found throughout on the surface. Most important easily accessible sites are:

1. Near the powerhouse at Canmore (51° 05' 20" N. latitude: 115° 22' 20" W. longitude), where over 7 feet of loess is situated on Bow Valley Till.
2. Along Route 1A about 1 mile northwest of Exshaw, where a few feet of loess with a 3-inch volcanic ash layer overlies bedrock.
3. Along the northeast side of Route 1 from the Banff National Park gate to Anthracite, where several thin patches of loess overlie till and outwash.

In all cases the loess is buff colored, calcareous, mainly unstratified, silty, fine-grained sand. Some platy parting was noted in places. The sorting is extremely

good (Figure 27). Sample N-70, from a loess patch overlying outwash near the southwest end of Lake Minnewanka ($51^{\circ} 14' 00''$ N. latitude; $115^{\circ} 31' 30''$ W. longitude), was analysed in the laboratory. It contains over 58% carbonates, with the rest being mainly quartz. With the carbonates removed, the grain size distribution is 6% clay, 48% silt, and 46% sand. Heavy minerals consist mainly of zircon, tourmaline, and chlorite, with lesser amounts of diopside and hornblende. The clay minerals are chlorite and illite. When compared with the fine fraction of till samples collected in the area, there is little difference between the two except in texture.

The premise that these deposits are loess and not lacustrine deposits is based on the following points:

1. The deposits occur as a surficial mantle following the contours of the topography.
2. They fill gullies, cover minor depressions, and adhere to steep slopes in areas where lake deposits would be unlikely to occur.
3. The deposits are not clearly stratified.
4. Some outcrops occur in close proximity and leeward to wind-blown sand (the deposit near Exshaw, for example).
5. The sorting and grain size of the Banff loess is similar to that of loess from other areas (Figure 27; Woldstedt 1954, p. 170-171).

Aeolian Sand

Although aeolian sand is present in small patches on glacial drift throughout much of the area of investigation, only one fairly large deposit was mapped. It is adjacent to the south shore of the Bow River, 2 miles east of Exshaw.

Generally, the patches of sand are stabilized at present. Most deposits probably originated during deglaciation or during the Altithermal.

Glacial Erratics

Some glacial erratics are found at altitudes above recognizable glacial de-

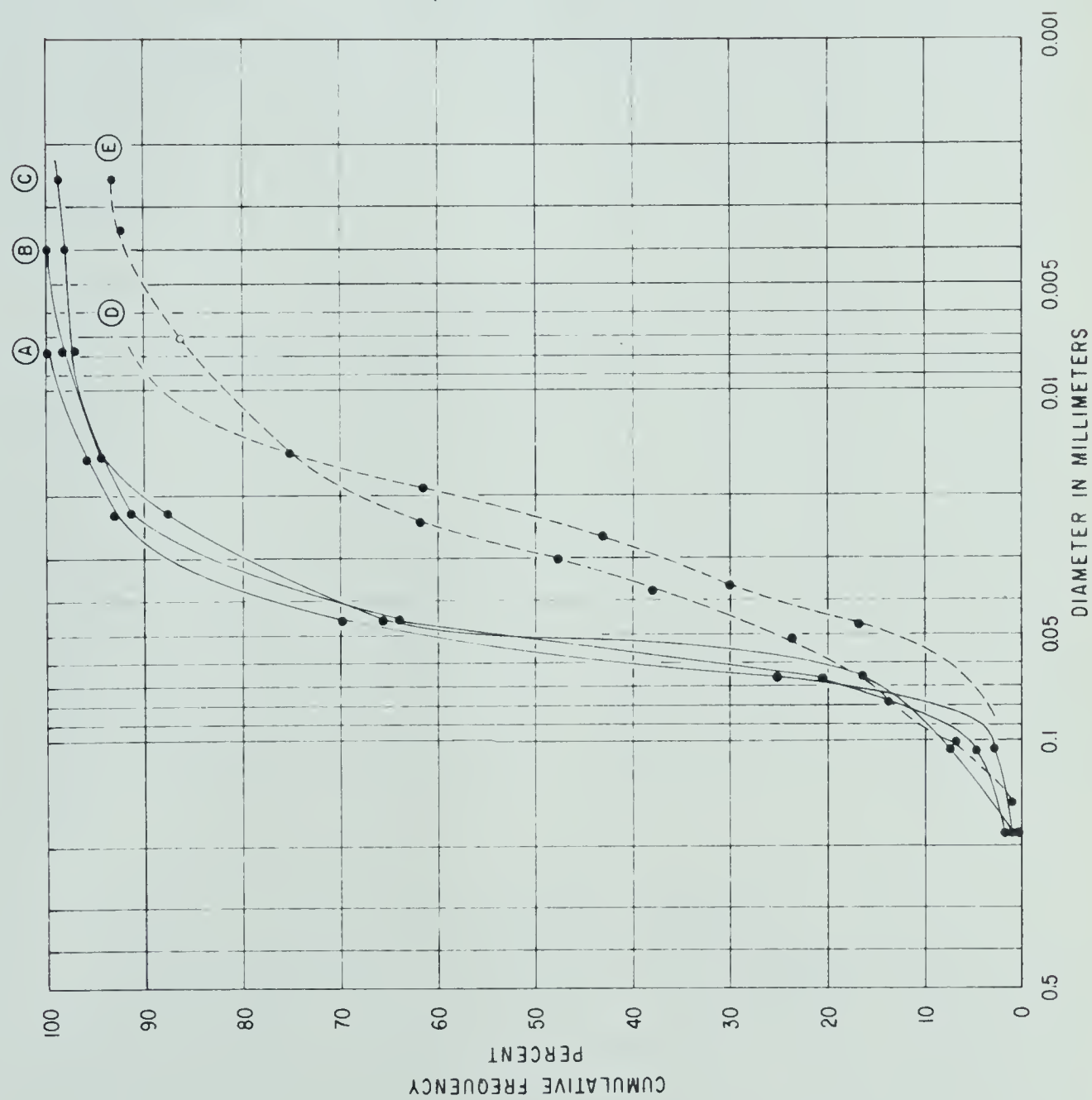


Figure 27. Cumulative-frequency curves of three loess samples from the Banff area (see sample location map) compared with curves from other areas (carbonates not removed).

posits. Warren (1927, p. 8) mentions that erratics are found at nearly 8,000 feet on Sulphur and Cascade mountains. The writer found erratics at over 7,400 feet on the crest of Sulphur Mountain, although it was not at the mountain's highest point. Erratics were not seen above 6,500 feet on the dip slope of Cascade Mountain. No glacial erratics were found on a saddle on Mt. Rundle at about 8,400 feet, on Grotto Mountain at about 8,800 feet, on a saddle near Mt. Charles Steward at about 8,000 feet, and on Mt. Eisenhower at about 8,700 feet. This lack of evidence indicates that the highest elevation of the ice in this area was probably not more than about 8,000 feet.

Post-Glacial Floodplain Alluvial Deposits

The Bow River floodplain and channel, whose characteristics are given in Chapter 2, contain the chief deposits of recent alluvium in the area under investigation. The sediments are mostly gravel, but lenses and patches of sand, silt, and clay also occur. Figure 28 presents subsurface data on the floodplain alluvium and associated deposits. The deepest drill-hole in Bow River alluvium, located on the southwest side of the Bow River bridge on Route 1 about 4 miles west of Banff penetrated 200 feet of sediment. Silty sand and gravel are the main deposits encountered here.

Other Surficial Deposits

Post-glacial talus, consisting principally of angular rubble, and alluvial fans and related alluvium, composed mainly of poorly sorted, angular and sub-angular gravels, with minor sand, silt and clay are common throughout the area. Less extensive deposits mapped as colluvium consist of bedrock rubble and some alluvium. Pond and organic swamp deposits consist of silt, clay and muck.

Landslide deposits are relatively scarce, but two interesting examples should be mentioned. One post-glacial landslide deposit located near Johnston Canyon, in part the result of slumping (described in Chapter 2), consists of angular fragments of Mesozoic sandstone and shale in a variety of sizes. In some exposures,

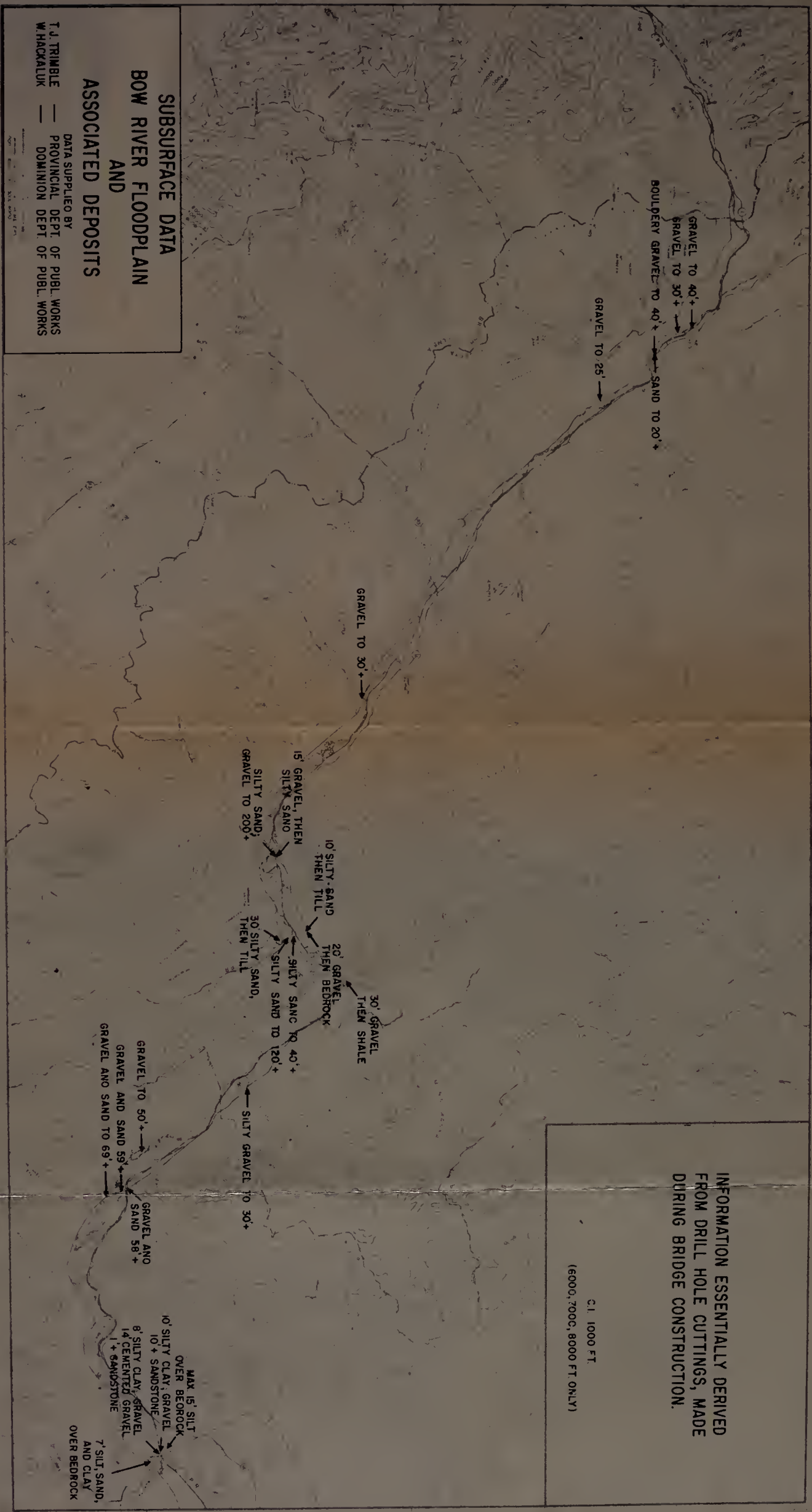


FIGURE 28

the fragments are so large that they can be mistaken for bedrock.

In the other occurrence, landslide material, consisting of locally derived rubble of various sizes and shapes, produced Moraine Lake by damming the valley at the northeast end. At least two generations of sliding are indicated by relative weathering and superposition of deposits. The deposits' shapes are most peculiar. Instead of appearing in a fan shape with an area of distribution many times the thickness, the rubble lies heaped in composite cones. This resulted from debris falling on the toe of a glacier and being concentrated by the movement of the ice. Hence, the deposits are in part ablation moraine.

Undifferentiated Surficial Deposits

A few areas have been mapped as undifferentiated surficial deposits (Maps 1, 2, and 3). In most cases they consist of glacial drift mixed with post-glacial colluvium and alluvium. Generally the deposits are thin and discontinuous, underlain by bedrock.

Conclusions

Study of the composition of the surficial deposits in the Banff area has led to the following conclusions concerning the Quaternary history and stratigraphy of the area:

1. The source of the glaciers affecting the study area was never beyond approximately 40 miles southwest of the Continental Divide, because rocks found west of there are not found in the till deposits of the Banff area. Rocks beyond 40 miles southwest of the Continental Divide consist of, among other things, acidic and intermediate intrusives such as granodiorite, granite, syenite, and monzonite. Glaciers that flowed in the Banff area most likely originated east of the Continental Divide.

2. Soil development and weathering characteristics of pebbles can not be used in differentiating till sheets. Present day soils are all fairly shallow (no soils

maps of the area are available; see Chapter 1), and paleosols were not found. The degree of weathering of rocks present in the tills is very small and difficult to determine.

3. The lithology of the pebbles of Eisenhower Junction Till is different from the other tills only because the former unit happens to occur entirely on grossly different bedrock. No other analyses show distinct differences among the tills of the area.

4. The distribution of tills suggests at least four glacial advances in the Banff area.

5. Non-ice-contact fluvial deposits in two different localities indicate two times of glacier equilibrium.

6. Glaciers in the Bow River valley in the Banff townsite area probably never reached an elevation of more than about 8,000 feet.

7. Stabilized wind-blown sand and dunes in the Banff area suggest drier and warmer Altithermal conditions (see next chapter).

8. Volcanic ash may be an important stratigraphic time indicator.

CHAPTER 5 - HISTORICAL GEOLOGY

General Statement

Stratigraphic information presented at the end of Chapter 2 and in Chapter 4, coupled with implications of drainage changes, absolute dates, and lithologic relationships, is used to construct a Quaternary sequence of glacial events. This sequence is then correlated with other areas.

Pre-Glacial Drainage and Topography

There is no reason to suspect that the ancestral drainage of the Bow River in the area under investigation was much different than that of today. As mentioned earlier, the Bow River is subsequent for most of its course, a normal situation at this stage of geomorphic development of the Rocky Mountains. Reasons for the Bow traversing the strike of the mountains (and therefore of the bedrock) in the lower part of its course can only be speculated upon. Since no faults or other bedrock phenomena that would cause the change are observed, it must be either an antecedent or a superposed river.

The idea that the Bow River may have flowed through Lake Minnewanka in pre-glacial time has been mentioned by several workers (Dawson 1886; Ogilvie 1904; Sherzer 1907; Warren 1927; and Allan 1943). This was speculative and never proved. The writer does not believe that the Bow River occupied different valleys in pre-glacial time, simply because the Bow River valley today is positioned in a relatively much more mature valley where it crosses the strike of the bedrock than the valley of Lake Minnewanka. The writer's idea on the origin of the present day morphology of the valley of Lake Minnewanka is discussed in a forthcoming paragraph.

Figure 29 illustrates the more obvious pre-glacial drainage courses in the Banff area which changed during the Pleistocene. These are:

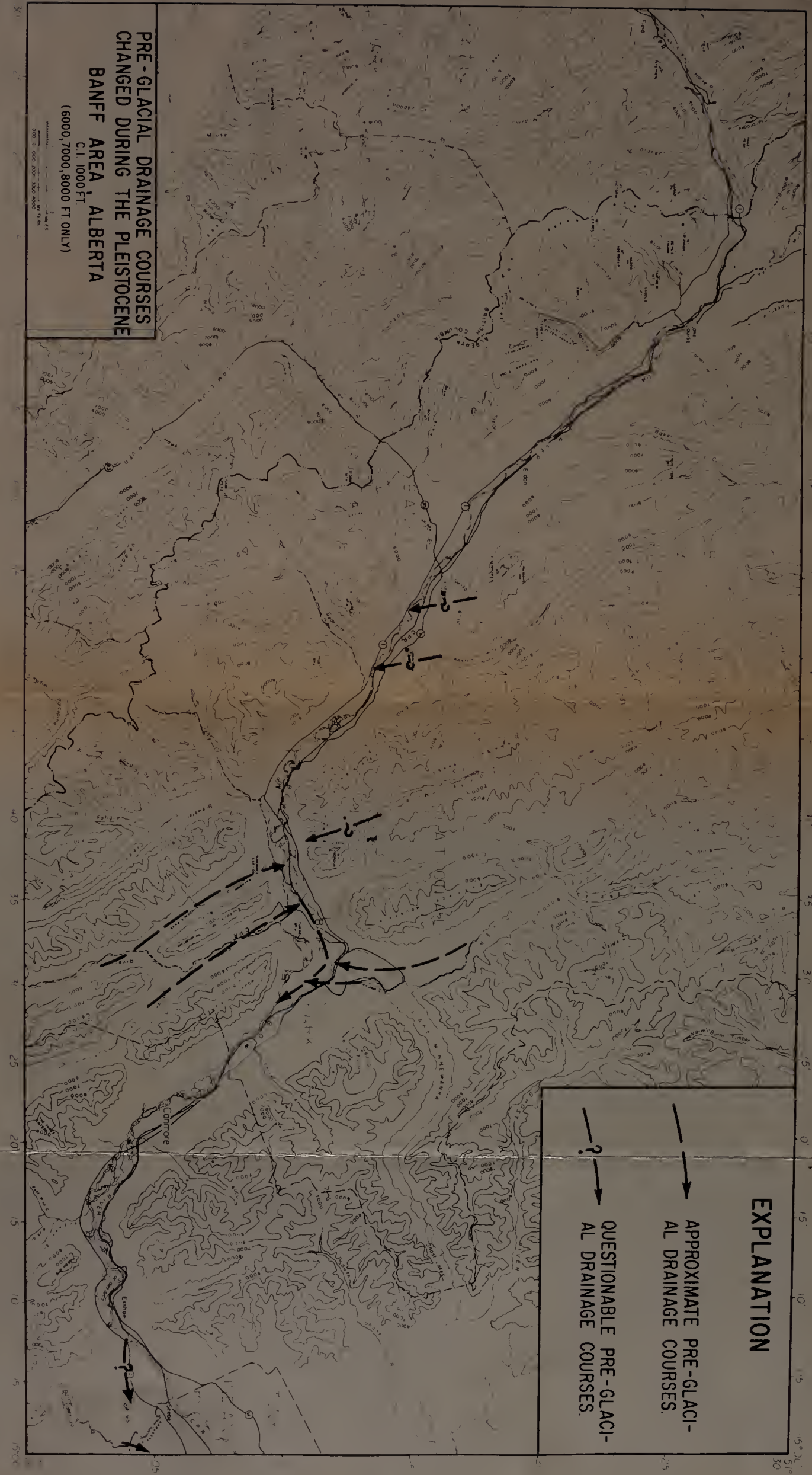


FIGURE 29

1. The Bow River flowed on the north side of Tunnel Mountain.
 2. The Cascade River probably flowed down the central portion of the Cascade valley, northwest of the southwest end of Lake Minnewanka.
 3. A river from Lake Minnewanka valley might have paralleled Two Jack Lake and entered the Bow River east of Banff townsite.
 4. The Spray River travelled down Sundance valley, entering the Bow River near Sundance Canyon.
 5. The lower part of the Spray River valley was occupied by Goat Creek.
- When and why these changes took place is explained later.

The mountains in the Banff area were probably more subdued, with gentler slopes prior to glaciation than those of today. The major valleys were probably V-shaped, relatively narrow, with higher gradients and more restricted floodplains. Erosion proceeded at a rapid rate in zones of less resistant rocks, since many of the larger valleys are cut through Mesozoic sandstone and shale. The local relief was similar but may be a little greater today due to glacial scouring.

Pleistocene Glacial Advances

General Statement

The number of glaciations or advances which took place in the Banff area prior to those to be discussed is difficult to estimate. Geochronological control and well-preserved glacial sediments in an area of high erosion suggest that all recognized glacial advances are relatively young, probably mid- or post-mid-Wisconsin. The presence of very fresh heavy minerals in the tills, such as hypersthene, support this conclusion also. Thus glaciation probably took place prior to the oldest recognizable advance but the obvious evidence has been lost or masked by subsequent advances.

Pre-Bow Valley Advance

The oldest advance recorded is named the Pre-Bow Valley advance. The lithologic evidence for it consists of outwash deposits underlying the Bow Valley Till near Banff townsite. Seventy feet of outwash was measured here (Appendix A, Section 1). These were presumably deposited during the retreat of the glacier up the Bow River valley and not during the next advance. This assumption is based on the commonly accepted premise that more ablation takes place during deglaciation than in an advance, resulting in more time for morainal material to be washed by fluvial action into outwash. Also, Tills A and B could be remnants deposited by this early ice. However their stratigraphic positions and outcrop elevations might also indicate that they were deposited by the next advance, the Bow Valley.

The position of the Spray River may have changed from Sundance Creek valley to approximately its present course during the deglaciation of the Pre-Bow Valley advance (Figure 29). The initial gap was probably caused by a side glacial stream flowing over a saddle into the Spray River valley when the ice was near the crest of Sulphur Mountain. During subsequent development of the gap, both fluvial and glacial erosion probably occurred. The only reason for placing the formation of the gap at this time is that it appears to have been glaciated since its development, and therefore was formed prior to the Bow Valley advance.

Bow Valley Advance

The Bow Valley advance is the most extensive that occurred in the Banff area for which clearcut evidence is available. Till deposits near Banff townsite, which are over 100 feet thick, are considered the main evidence for this advance although Bow Valley Till is widespread throughout the Banff area from southeast of Eisenhower Junction to the Kananaskis River (Map 5). The Bow valley glacier probably originated on the east side of the Continental Divide and near the divide

of the Bow River drainage system and the Mistaya River drainage. Evidence presented in Chapter 4 indicating that no rock types foreign to the Rocky Mountains occur in the till of the Banff area substantiate this statement.

Erratics found along the crest of Sulphur Mountain and on Cascade Mountain were probably derived from Bow valley ice, although they could have been deposited earlier. Positions of erratics indicate that Bow valley ice reached no higher than about 8,000 feet in the Banff townsite area. Breaks in slope caused by glacial erosion and side glacial stream action, and glaciated surfaces found in the highest positions on the valley sides are believed to be Bow valley in age and to represent the upper limit of Bow valley ice. These occur in the Alpine Region physiographic unit, at a maximum elevation of 8,200 feet in the area of The Valley of the Ten Peaks and a maximum of 7,600 feet on the east side of the Baker Creek valley (Table IV). Escape channels and associated gravels present near the upper reaches of Johnston Canyon indicate that the upper limit of the Bow valley glacier at one time was about 6,800 feet (Map 1).

Therefore, during the Bow Valley advance, the ice was largely, but not wholly, confined to valleys, with the flow of the ice controlled by the topography; hence, it may be called a reticulated glacier. The minimum thickness of the ice in the northwest part of the area varied between about 1,600 and 2,600 feet during the maximum extent (Table IV). There is no indication of a terminal moraine in the Bow River valley. The ice probably extended eastward well beyond the Kananaskis River.

The glacier in the valley of Lake Minnewanka flowed mainly westward into the Cascade River valley glacier, which in turn flowed into the Bow valley glacier (Plate XVI). The westward movement is difficult to prove, but some facts support this theory: the natural gradient today is toward the west; the U-shaped valley widens toward the west; and toward the east end of the valley, mountains are found above 8,000 feet, in which cirque glaciers developed and supplied the main

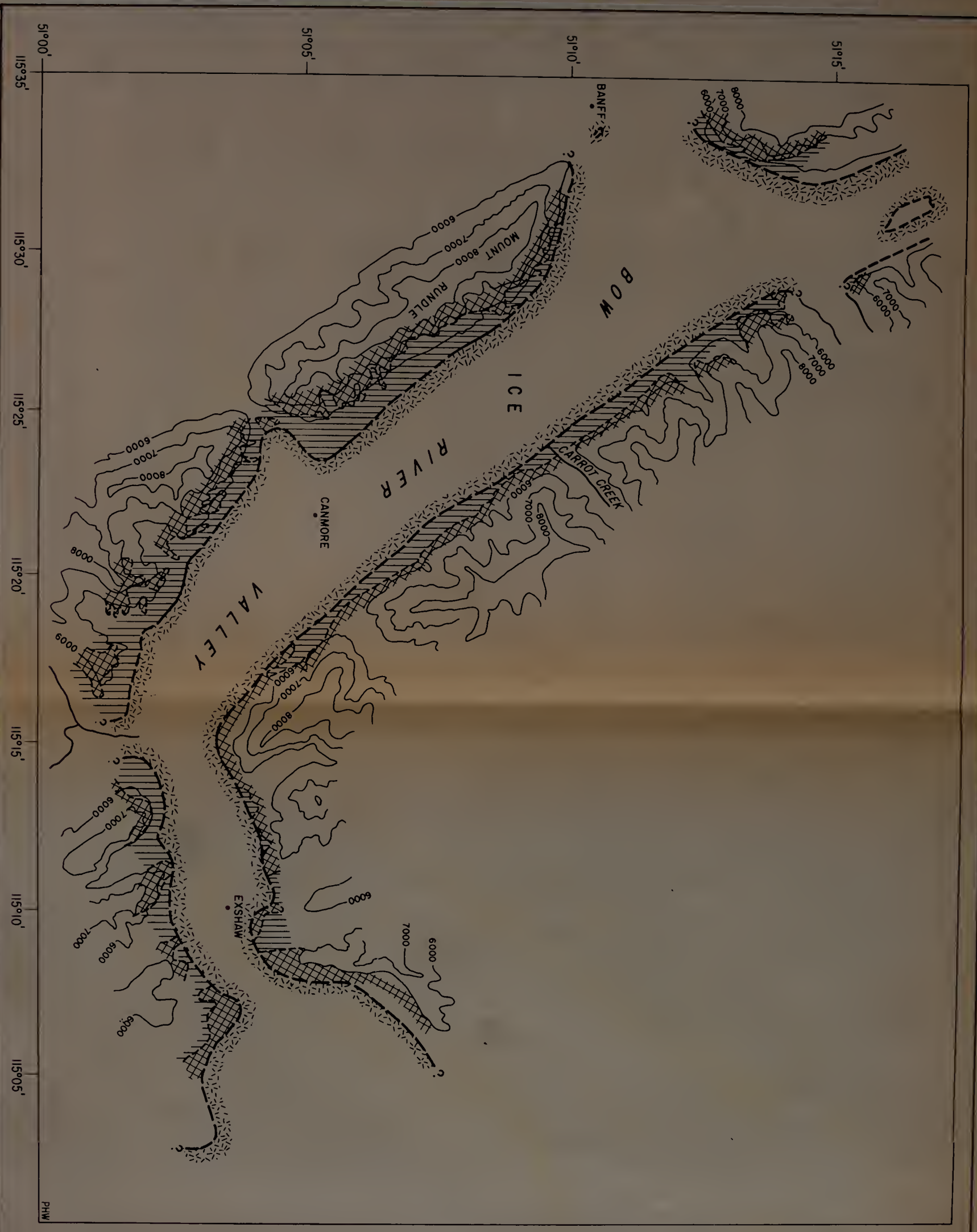
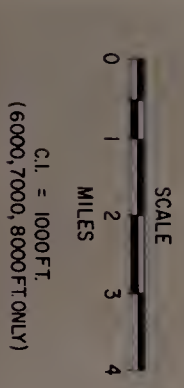


FIGURE 30
 MAXIMUM EXTENSION OF THE
 BOW VALLEY RE-ADVANCE,
 SE. BANFF AREA



- EXPLANATION**
- KNOWN OR APPROX. ICE-LIMIT
 - ASSUMED ICE-LIMIT
 - BOW VALLEY TILL OR OLDER
 - BEDROCK-SOME WITH COLLUVIUM AND/OR GLACIAL ERRATICS
 - DEFINITE CONTACTS
 - APPROXIMATE CONTACTS
 - ASSUMED CONTACTS

valley glacier with ice which, because of this source, would probably flow westward.

Evidence exists for two equilibrium phases during deglaciation. Near Canmore ice-contact fluvial deposits (originally kame moraines) grade into outwash plains both upvalley and downvalley from the ice-contact material. Near the confluence of the Bow and Cascade Rivers, ice-contact outwash grades into Bow Valley Till upstream and into outwash downstream (Maps 2, and 5).

The gap above Canmore on Mt. Rundle was probably caused by meltwater eroding an escape channel during the deglaciation of the Bow Valley advance (Map 2).

Bow Valley Re-advance

The maximum extent of the Bow Valley re-advance in the southeastern part of the Banff area is illustrated in Figure 30. The ice in the Bow River valley apparently retreated before the re-advance to at least the area of the confluence of the Bow and Cascade Rivers. The ice-contact outwash located here may represent the pause before the re-advance. Breaks in slope caused by glacial erosion and side glacial stream activity located along one discontinuous line on the southwest side of the Bow River valley are evidence for the re-advance. Near the Banff National Park boundary, the breaks are at a maximum of 5,300 feet, and near Canmore, at a maximum of 5,100 feet (Map 2, Table VI, Figure 7). The ice was then approximately 750 feet thick in these places.

The best evidence for the re-advance, however, is thin, discontinuous patches of till (not mapped) located on the surface and overlying the outwash deposits laid down during the deglaciation of the Bow Valley advance. Also, till sheets with erosional ridges probably underlain by glacial outwash found southeast of the confluence of the Bow and Cascade Rivers were probably formed during the re-advance.

The features of the kame moraine physiographic unit may have originated by deglaciation following the Bow Valley re-advance, if it extended this far. Escape

channels, elevated bedrock terraces, and drift-covered bedrock knobs are at lower elevations than the surface of the glacier would have been in this area while depositing the kame moraine. The elevation of the surface of the glacier is estimated by comparing the elevations of the breaks in slope, formed during the Bow valley re-advance, located up the Bow River valley not far from this area.

An ice slab was probably left behind at the narrow gap near Exshaw during the retreat. This caused damming of the Bow River causing glacial Lac des Arcs to expand. When the ice slab ablated farther, damming by the slab stopped, exposing the higher sediments of glacial Lac des Arcs, remnants of which are above the present level of the lake today.

The Bow River probably cut its present day course through the Kame Moraine Region after the deglaciation of this area. The river is youthful here, as evidenced by its restricted floodplain and bedrock channel. Also, the Kananaskis River was probably diverted to its present course at about this time by glacial drift damming its route farther to the east. Before the area was glaciated, the Kananaskis River probably flowed through Lake Chinike (out of study area) and entered the Bow River farther downstream. Morphology suggests this previous route.

As deglaciation continued up the Bow River valley, a side glacial stream (the present route of the Bow) was flowing around the south side of Tunnel Mountain (then the end of Mt. Rundle). This channel most likely formed at this time, since Bow Valley Till crops out northeast of Banff townsite wherever the Bow River might have been expected to flow, except in a narrow gap about 2 miles northeast of Tunnel Mountain where the present day Cascade River drains. The gap probably could not accommodate the amount of water that must have been present during deglaciation.

As a side glacial stream was cutting through Tunnel Mountain, drainage changes were taking place in the Lake Minnewanka area. First, the Lake Minnewanka valley was apparently ice-free, at least at its southwest end, while ice remained

in the Cascade and Bow River valleys. This is based on the assumption that deglaciation would affect the east-to-west-flowing Lake Minnewanka glacier first, due to the geographical source of the ice supplying the glaciers concerned. A side glacial stream was able to excavate bedrock in the northeastern part of the Cascade River valley during deglaciation and flow into Lake Minnewanka valley (Map 2). This permanently shifted the Cascade River out of the center of the valley in this area. An abandoned stream canyon and waterfall that flowed into the valley of Lake Minnewanka were uncovered by the Calgary Power Company in the early 1940's during the construction of a dam in the area where the present Cascade River leaves Lake Minnewanka (Map 2). Calgary Power removed the overburden from the gorge and contoured it before burying it once again during dam construction (Figure 31, Plate XV B). Meltwater from the Cascade valley glacier began eroding the canyon and flowing into Lake Minnewanka valley when the northeast flank of the glacier was at least as high as the bedrock above the canyon and old waterfall. This would have to be after the side glacial stream began cutting along bedrock on the northeast side of Cascade valley, as mentioned in the last paragraph, because more melting would have had to take place in the Cascade valley glacier in order to have the area of the canyon exposed (Map 2). Erosion of the canyon could not keep pace with the melting ice, and soon the waterfall was abandoned, and drainage shifted to the west. (Notice contours in the west side near the top of the old waterfall, Figure 31).

The top of the old waterfall is at 4,753 feet, and the Cascade River entering Lake Minnewanka was at 4,769 feet prior to artificial damming of the lake (Allan 1943, p. 2). The floor of Devil's Gap at the eastern end of Lake Minnewanka has an elevation of 5,050 feet. Therefore, in order for meltwater from Cascade River valley and the uncovered canyon to flow through Lake Minnewanka valley from west to east, it would have been necessary to lower the surface of the floor of Devil's Gap by at least 297 feet or raise the water level near the waterfall the same



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Figure 31. Contour map of excavated abandoned stream canyon and face of old waterfall near outlet of the Cascade River from Lake Minnewanka ($51^{\circ}14'30''$ N. latitude; $115^{\circ}29'40''$ W. longitude).

amount. Possibly something like this happened. Before the Cascade valley glacier thinned to the point at which the waterfall and canyon developed, the Lake Minnewanka glacier acted as a dam, forming glacial Lake Minnewanka. Glacial drift at the eastern end may have contributed to later damming also, since remnants of glacial drift are present in Devil's Gap today. When the eastern dam broke, erosion of till and perhaps bedrock near Devil's Gap took place. As the water level was lowered, the waterfall and canyon developed, but they were probably short-lived, as evidenced by the canyon's limited dimensions. As the energy level decreased further, aggradation near Devil's Gap shifted the drainage to the west.

As ablation continued in the Banff townsite area Cascade valley glacier separated from Bow valley ice. The Bow valley glacier then blocked the lower Cascade River, forcing it to cut a gap through glacial drift and bedrock to the southeast along its present day route (Map 2). As the Bow valley ice retreated farther, the Cascade abandoned that course and flowed near the present Whiskey Creek and joined the Bow. Later when the volume of water was decreased, the area near Whiskey Creek was aggraded by such phenomena as an alluvial fan extending from Forty Mile Creek. This choked the Cascade River and forced it to its former position along the gap about 2 miles northeast of Banff townsite, its present day course.

The glacial drift and lake deposits upstream from Tunnel Mountain in the Spray River valley may have been deposited at about this same time.

It is believed that the deglaciation of the Bow Valley re-advance was very extensive, because evidence for the succeeding advance is found near the source of the ice. Perhaps only a few of the more protected cirques contained ice before the Eisenhower Junction advance.

The absolute age of the Bow Valley re-advance has not been determined as yet. Fossils found in the emerged lake deposits on the north shore of Lac des Arcs and identified by Dr. R. Green, Research Council of Alberta (personal communication are:

Gastropods

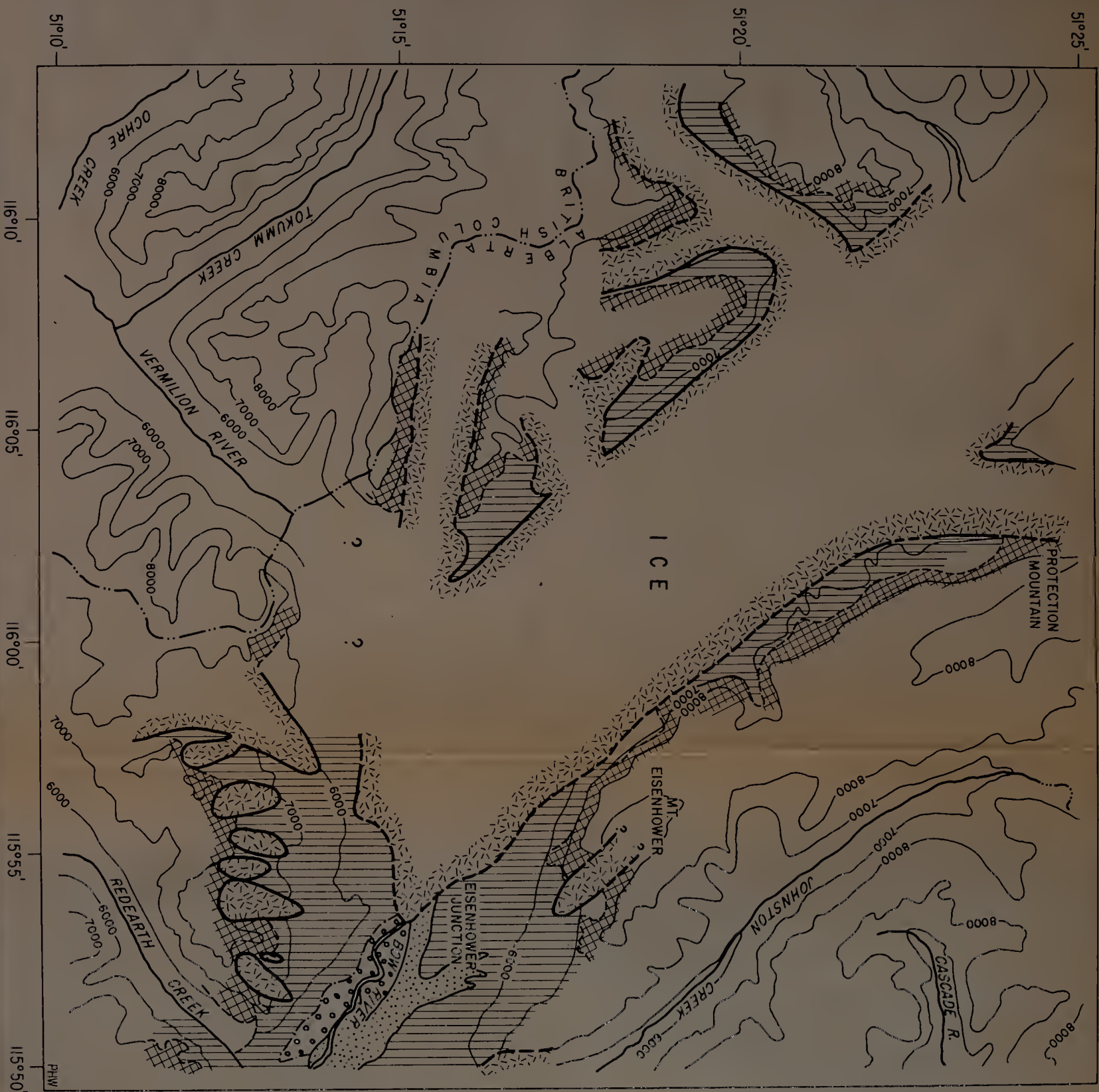
Discus cronkhitei (Newcomb)Discus shlmeki (Pilsbry)

Both are terrestrial, ranging in time from at least the Yarmouthian Inter-glacial to the Recent. Today Discus cronkhitei ranges from Alaska to Labrador and as far south as Maryland and Arizona. Discus shlmeki at present ranges from Arizona to Montana through the western half of Alberta to the Yukon and southward to Nevada away from the Pacific Coast. Both species are absent from the United States Great Plains, the controlling factor being the dryness of the climate. At the time of their existence, the climate of the Bow Valley could have been the same, warmer, or cooler, but not much drier than today.

Peat was collected for radiocarbon dating from a glaciated bedrock bench about 400 feet above the Bow River about 2 miles southeast of Canmore (51° 03' 00" N. latitude; 115° 18' 40" W. longitude). The sample was collected at the base of a 4 1/2 foot section of peat that underlies 6 inches of lake silts and overlies bedrock. It should give a fairly accurate date for the beginning of peat bog development and hence a minimum age for the Bow valley re-advance. The peat was dated at 5560_± 130 years B.P. (G.S.C. -360). Another minimum date determined for a younger advance upvalley is almost twice as old as this. Thus, this peat bog began developing long after the deglaciation of the area.

Eisenhower Junction Advance

More is known concerning the Eisenhower Junction advance than any advance previously discussed. This is due principally to good preservation of deposits and some geochronological control. The name "Eisenhower Junction" is taken from the most prominent geographical location nearest the point where the advance terminated in the Bow River valley. Figure 32 illustrates the maximum extension of this advance in the area under investigation.

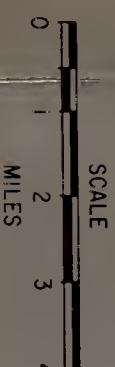


EXPLANATION

- KNOWN OR APPROX. ICE-LIMIT
- ASSUMED ICE-LIMIT
- BOW VALLEY TILL OR OLDER ALLUVIUM
- UNDIFFERENTIATED SURFICIAL DEPOSITS
- BEDROCK-SOME WITH COLLUVIUM AND/OR GLACIAL ERRATICS
- DEFINITE CONTACTS
- APPROXIMATE CONTACTS
- ASSUMED CONTACTS

FIGURE 32

MAXIMUM EXTENSION OF THE
EISENHOWER JUNCTION
ADVANCE



C. I. = 1000 FT.
(6000, 7000, 8000 FT. ONLY)

The ice originated in the area of the Continental Divide, the head of the Bow River valley, and certain cirques in the northwestern part of the study area. These cirques are fairly fresh, with floors between 6,000 and 7,000 feet in elevation. In the cirque succession series, these are the lowest cirques (Table III).

The upper limit of the glaciers during this advance is well marked by lateral moraines in Consolation Valley and The Valley of the Ten Peaks (maximum elevation about 7,500 feet), and breaks in slope due to glacial erosion and side glacial stream activities in the southwest side of the Bow River valley (maximum elevation about 6,750 feet). Less convincing evidence appears as breaks in slope in the Baker Creek valley and the northeast side of the Bow River valley (Maps 1 and 5; Table VI). The upper limits of this advance also delineate the boundary of the Alpine Region and Major Valleys physiographic units. The maximum ice thickness in the Bow River valley was about 1,900 feet.

Ground and lateral moraine were deposited widely in the lower parts of the main valleys during the retreat of the Eisenhower Junction glaciers. Only one till sheet has been differentiated. Tills of different advances may be present but cannot be identified as such because of poor exposures and lithologic similarity of tills of varying ages (see Chapter 4).

Near Eisenhower Junction, the till grades into an ice-contact fluvial complex believed in part to represent the terminal moraine of this advance. No lateral moraines and prominent extensive breaks in slope appear downvalley from Eisenhower Junction to Banff townsite (Maps 1 and 2). A number of fresh cirques and glacial troughs which did not contribute ice to the Bow River valley are located in the vicinity of and northwest of Eisenhower Junction. If the Eisenhower Junction advance extended beyond the boundaries proposed here, fresh cirques and glacial troughs would probably be abundant southeast of the Eisenhower Junction area. Alluvial fans from tributary creeks as well as the Bow River floodplain are less well developed upstream from Massive than downstream (see Chapter 2), sugg-

esting relatively less development time for the upstream forms.

Therefore, the evidence for a separate glacial advance that flowed as far as Eisenhower Junction is not based on a distinctive till or stratigraphic sequence, but rather on geomorphology and related glacial deposits.

Eisenhower Junction Re-advance

Evidence for a minor re-advance of the waning glaciers of the Eisenhower advance consists of till lenses a few feet thick overlying ice-contact outwash near Altrude Creek. Other evidence consists of four equivalent breaks in slope on the east side of Baker Creek valley and the northeast side of the Bow River valley below the upper limit of the Eisenhower Junction advance (Table VI). Glacial erosion and glacial stream activity have slightly altered the morphology within the main depressions of a number of cirques located about 3 miles south of Eisenhower Junction. These may have been ice-free between the main advance and re-advance and did not support large glaciers during the latter. The limit of ice in these cirques during the re-advance are indicated where possible, on Maps 1 and 5.

The amount of deglaciation in the major valleys and the time lapse before the re-advance are not known. The downvalley extension was probably not much farther than the main advance, since all evidence suggests less glacial activity. This was the last glacier present in the Bow River valley in the area under investigation.

Some geochronological control can be placed on the Eisenhower Junction re-advance. No material from the area has been found for absolute age dating, but charcoal from a location on the north side of the North Saskatchewan River next to the bridge on Route 93 in Banff National Park ($51^{\circ} 58' \text{ N. latitude}$; $116^{\circ} 43' \text{ W. longitude}$) has been dated at $9,330 \pm 170$ years B.P. (G.S.C.-332; Courtesy A. Dreimanis and J.A. Westgate). This site is located in the upper part of the North Saskatchewan drainage system, less than 20 miles from the east-west divide separating this drainage system from that of the Bow River.

The charcoal was collected from the following stratigraphic section (J.A. Westgate, personal communication):

0 - 2 feet - Modern soil.

2 - 8 feet - Loess with two volcanic ash layers.

Wood fragments from a volcanic ash layer located nearby ($51^{\circ} 59'$ N. latitude; $116^{\circ} 47'$ W. longitude), probably correlative with one of these, were dated at $6,020 \pm 90$ years B.P. (S-191; Courtesy A. Dreimanis and J.A. Westgate).

Detrital charcoal occurs near the base of the loess (material dated at $9,330 \pm 170$ years. B.P.).

8 - 30 feet - Glacio-fluvial deposits.

North Saskatchewan River level.

It appears that the section is complete and that the lithology represents the latest glacial deposits in this part of the North Saskatchewan River valley. The stratigraphy suggests a deglaciation phase.

The charcoal is found along a single bedding plane in the lower part of the loess section. It consists principally of small pieces of burnt twigs, although fragments as large as 3 inches are found. Therefore, the charcoal has probably not been moved far because of the size of the fragments and represents a minimum age for ice in this area. Although only one date is available, there is a good possibility that it can be considered the minimum age of the Eisenhower Junction re-advance. This conclusion is based on the geographical location of the two areas, both of which are located near the Continental Divide, in the same climatic zone, and therefore were probably glaciated at the same time. Also, the section containing the charcoal sample and the deposits of the Eisenhower Junction re-advance represent the latest glacial deposits in each of the two areas.

Volcanic Ash Layers

Reference has been made to volcanic ash layers found in the Banff area.

Since all appear in wind-blown deposits near the present surface and have about the

same thickness and stratigraphic position, they are believed to represent the same ash fall. Two ash layers have been mentioned that are found in succession in the loess near the North Saskatchewan River crossing, and one below an alluvial fan which was dated at $6,020 \pm 90$ years B.P. Since it appears that a small interval of time separates the two layers, a date of around 6,000 years seems appropriate for both. The ash layer in the Banff area should correlate with one of these.

Since the ash is associated with wind-blown material, it appears to have fallen during a time of sparse vegetation. This could mean, a drier, warmer period, probably the Altithermal. The date of about 6,000 years for the ash concurs with the dates presently considered for the Altithermal -- 4,000 to 6,500 years B.P. (Richmond 1965, p. 227).

Recent Glacial Activity

Recent glacial activity is defined here as any glacial activity after the Eisenhower Junction re-advance. Probably most is post-Altithermal in age, but proof can be given in only one instance. The writer did not concentrate on deciphering in detail post-Altithermal glacial activity.

One line of evidence for recent glacial activity includes the middle and upper cirques of the cirque succession (Table III), which best represents an overall ascending climatic snowline in relatively recent times. The lower cirques were the source of ice for the Eisenhower Junction re-advance and certain older advances. Hence the middle and upper cirques developed subsequently.

Other evidence for post-Eisenhower Junction glacial activity is moraines of limited extent associated with existing glaciers or relatively recently vacated cirques. The relationship between these moraines and the middle and upper cirques is unknown, because the glaciers associated with the deposits may or may not have formed the cirques they are now occupying or recently occupied. If these glaciers did form their own cirques, it would still be difficult or impossible,

in this situation, to determine which cirques they were equivalent to within the succession.

What may be the most extensive recent moraine associated with an existing glacier or a recently vacated cirque is a forest covered till deposit which rises gently above the southeast side of Moraine Lake to the ice-cored moraine of the Wenkchemna Glacier (Map 5). Only the morphology of the deposit indicates a separate unit. Tree ring counts indicate that the oldest trees are about 105 years old. If this is added to an amelioration period of 12 years (Heusser 1956, p. 275), the till is at least 117 years old.

Two juxtaposed forested end moraines, indicating other recent glacial activity, protrude from the toe of the Horseshoe Glacier (not in the mapped area), and their probable equivalents have been observed in Larch valley about 1 mile north of Wenkchemna Glacier (L.A. Bayrock, personal communication).

Ice-cored end moraines, which are believed to represent a relatively recent advance, border the Wenkchemna Glacier and the glaciers at the head of Consolation and Boom Creek valleys.

Sherzer (1907, p. 68-69) noted two distinct composite "moraines," adjacent to and partially underlying the ice-cored moraine of Wenkchemna Glacier and named them the Bear-den moraines. They are actually two or more generations of landslide deposits (Maps 1 and 5) for the following reasons:

1. Huge blocks are predominant, and fine-grained material absent.
2. The material (greenish and reddish argillite and quartzite) is locally derived.
3. Scars in the bedrock on the south wall of the valley indicate the source of the material.
4. The shape of the units, irregular sheets following the contours of the pre-existing topography, favor a landslide origin.

Heusser (1956) studied post-glacial environments in the Canadian Rocky

Mountains in detail, utilizing information on the activity of present day glaciers and paleobotanical evidence. His most important conclusions (1956, p. 289) were:

1. Between 1350 and 1650, a major advance was in progress, with the maximum reached mainly during the first quarter of the eighteenth century. Recession began in the last quarter and ended in the early 1800's.

During the first half of the nineteenth century, a major re-advance occurred, some glaciers exceeding the limits of the earlier maximum. Recession has prevailed since the mid-nineteenth century, although minor re-advances and changes in the rate of recession are indicated.

3. During the late 1800's in some instances and the early 1900's in others, retreat was relatively rapid.

4. In the early 1900's, the rate of recession decreased.

5. Since about 1930, recession has been more rapid.

6. Since the late 1930's, temperatures have fallen and precipitation risen (Heusser 1956, p. 268), suggesting a regeneration of glacier growth.

The ice-cored end moraine of Wenkchemna Glacier resulted from the recession of a nineteenth century re-advance because the moraine, when compared with the map prepared by Sherzer (1907, Plate XXII) in 1904, has changed very little morphologically, and if the re-advance was earlier than the nineteenth century, more disintegration of the ice-cored moraine would be expected, with vegetation taking hold as is the case with the earlier moraines on Robson Glacier (Heusser 1956, p. 276).

Correlation

The best understood area in the Rocky Mountains that can be logically correlated with the Banff area is the northern United States Rockies (Figure 33). A sequence of glacial events in the mid-continent area (Frye and Willman 1960) is presented for gross correlations only.

Figure 33. Correlation chart of Banff area, Alberta, and the United States Rocky Mountains and Mid-continent Region.

*Banff area, Alberta (this report)	Approx. age B.P.	Rocky Mountains after Richmond (1965)	Approx. age B.P.	Midcontinent Region after Frye & Willman (1960)
Nineteenth Century Advance Recent Advances? (Forested moraines, etc.)	800 900	Neoglac- iation	Gannett Peak Stade Interstade Temple Lake Stade	Recent
Altitheermal Interval (Ash Layer 6, 020±90yrs. B.P.)	4,000 6,500	Altitheermal Interval		
? Eisenhower Junction Re-advance (Min 9,330+ 170 yrs. B.P.)				
Eisenhower Junction Advance	10,000	Pinedale	Late Stade	Valderan Substage
	12,000		Interstade	Twocreekan Substage
Bow Valley Re-advance		Glaciation	Middle Stade	Woodfordian Substage several advances
			Interstade	
Bow Valley Advance	25,000		Early Stade	Farmdalian Substage
	32,000	Interglaciation		Altonian Substage
Pre-Bow Valley Advance or Advances ?	45,000	Bull Lake	Late Stade	
			2nd episode Nonglacial interval	
			1st episode Nonglacial interval	
		Glaciation	Early Stade	
		Interglaciation		Sangamonian Stage
		Sacagawea Ridge Glaciation		
		Interglaciation		Illinoian Stage
		Cedar Ridge Glaciation		Yarmouthian Stage
		Interglaciation		Kansan Stage
		Washakie Point Glaciation		Aftonian Stage
				Nebraskan Stage

* Radiocarbon dating control only where indicated

The Pre-Bow Valley advance is correlated to the Bull Lake Glaciation only because pre-Bow Valley gravels deposited by the Pre-Bow Valley advance are in contact with Bow Valley Till. Evidence for earlier advances may eventually be found in the Banff area.

The three stades of the Pinedale Glaciation are correlated with the Bow Valley advance, Bow Valley re-advance, and the Eisenhower Junction advance. Although absolute age control is poor, several lines of evidence are convincing:

1. Moraines of the early and middle stades of the Pinedale lie in large piedmont lobes at the mountain front in north central Montana (Richmond 1965, p. 224). In the Banff area, the glaciers of the Bow Valley advance and re-advance flowed beyond the Front Ranges, forming piedmont lobes.

2. Moraines of early and middle stades of the Pinedale Glaciation commonly lie close together in the United States Rockies, whereas the moraines of the late stade lie at some distance upvalley (Richmond 1965, p. 224). In the Banff area, the Eisenhower Junction advance terminated well up the valley, and the Bow Valley advance and re-advance, as mentioned previously, flowed out of the mountains.

3. If Richmond's (1965, p. 224) curve of the average altitude of the late Pleistocene and Recent end moraines in the United States Rocky Mountains is extended to the 51st north latitude line (Banff area), the end moraines of the Pinedale stades should fall at altitudes of about 4,000, 4,600, and 4,800 feet respectively. The Bow Valley advance was at least at 4,000 feet, the Bow Valley re-advance is estimated at about 4,200 feet, and the Eisenhower Junction advance definitely terminated at about 4,750 feet.

4. During the interstade separating the early and middle stades of the Pinedale Glaciation, recession of the glaciers ranged from almost none to a few kilometers (Richmond 1965, p. 226). This indicates that glaciers did not completely leave the major valleys during the interstade. In the Banff area, the recession of

the Bow valley glacier was to about Banff townsite before the re-advance. In other words, the glacier did not leave the major valley during the recession.

5. The Altithermal is represented by an immature zonal soil and a volcanic ash layer (Mt. Mazama ash) in or on the soil in the United States Rockies (Richmond 1965, p. 225-226). Organic matter above or below the ash in Oregon and Washington was dated at about 6,600 years B.P. This ash is now considered equivalent to the Galata ash found in the Waterton area, Alberta, by Horberg and Robie (1955). (Powers and Wilcox 1964). In the Banff area, ash of about the same age is associated with the wind-blown deposits. This probably represents the Altithermal.

Correlation between the post-Altithermal glacial events of the United States Rockies and the Banff area is questionable. Two minor glacial advances, the Temple Lake Stade and Gannett Peak Stade in the United States Rockies, may be equivalent to the middle and upper cirques of the Banff area. The Temple Lake Stade is represented by two moraines that support tundra vegetation and scrub spruce (Richmond 1965, p. 226). These may be equivalent to the moraines near Moraine Lake, near the Horseshoe Glacier, and in Larch Valley. Horberg (1954, p. 1,137) noted a fresh cirque moraine, probably not much less than 3,300 years B.P. (p. 1,140) in the Waterton area, Alberta. This may correlate with one of the above.

The Gannett Peak Stade is represented by fresh moraines in front of existing glaciers or recently deglaciated cirques (Richmond 1965, p. 226). Ice-cored moraines in the Banff area of the nineteenth century advance (and moraines of other advances of the last few centuries in the Canadian Rockies) are equivalent to the Gannett Peak Stade.

The elevation difference between the present orographic snowline and that of the Bull Lake and Pinedale Glaciations (Richmond 1965, p. 228) is up to 2,000 feet. A difference of at least 1,800 feet is noted between the estimated present orographic snow line of three existing glaciers in the Banff area and elevations of cirque floors in the same valleys occupied by glaciers during the time of the Eisenhower Junction

re-advance, or previously.

Correlating Pleistocene stratigraphy of the Banff area with continental glacial deposits of the Alberta plains is speculative, because the area of investigation does not include any continental deposits. Outside the Front Ranges in Alberta, several workers have noted that the Cordilleran drift invariably underlies the oldest continental drift seen, with some authors mentioning that two glaciations originating in the mountains have flowed into the plains (Dawson and McConnell 1895, Coleman 1910, Nichols 1931, Horberg 1954, Tharin 1960). Horberg's (1954) work in the Waterton area, Alberta, is probably the best documented. He equates his early Wisconsin mountain drift to the Bull Lake and his late Wisconsin mountain drift which underlies the first deposits of continental drift, to the Pinedale (p. 1, 140). Richmond (1965, p. 225) says these deposits are equivalent to the early stage of the Pinedale.

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APPENDIX A

Section I. Powerhouse Section -- Bow Valley Till overlying pre-Bow Valley glacial (51° 11' 40" N. latitude; 115° 31' 00" W. longitude).

		Thickness	Depth
Bow Valley Till	Soil:		
	Till: Lt. olive gray (5Y6/1) yellowish gray (5Y7/2) when oxidized; firm; unsorted; 80% calcareous; sandy clay loam; 15-20% gravel, angular to well rounded (mostly subangular) pebbles, some striated and oriented with their long axes parallel or nearly parallel to the direction of glacier movement; mode 10-40 mm., less than 1% boulders; mostly limestone and dolomite stones with lesser amounts of quartzitic sandstone, quartzite and chert.	2'	0'- 2'
	Gravel: Gray-brown; moderately sorted; 85% pebble-sized or larger; mode 20-40 mm.; rock-type as above.	19'	2'- 21'
	Till: As till above.	2'	21'- 23'
		80'	23'-103'
pre-Bow Valley outwash	Gravel: Gray-brown; poorly to moderately sorted; 80% pebble sized or larger; mode 10-40 mm.; angular to well rounded, mainly subrounded; partly graded, poorly bedded few boulders over 1 foot; dip S55°E less than 3°; rock-types same as till above.	37'	103'-140'
	Gravel?: Covered.	33'	140'-173'

Section II. Ice-contact fluvial deposits -- Eisenhower Junction advance (51° 15' 40" N. latitude; 115° 56' 40" W. longitude).

Gravel: Gray-brown; very poorly sorted; 50% pebble-sized or larger (10% boulders, 15% cobbles 25% pebbles); mode about 75mm.; largest boulder 4 feet long; subangular to subrounded fragments; poorly bedded; fragments consist mainly of shale (argillite), quartzitic sandstone, limestone and dolomite; regional dip S35°E. 5-10°.	12'	0'- 12'
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	Thickness	Depth
Gravel: Gray-brown; poorly sorted; 60% pebble-sized or larger (55% pebbles); mode about 75 mm.; largest boulder 1 foot; subangular to subrounded fragments; dip and rock-types as above.	7'	12'- 19'
(A) Gravel: Gray-brown; moderately sorted; 80% small pebbles to granules; mode 6-12 mm.; largest pebble 80 mm.; mainly subrounded fragments; 20% sand or smaller; dip S60°E 24°; rock-types as above.	1'	19'- 20'
(B) Gravel: Lt. brown; moderately sorted; 50% pebble-sized or larger (mainly pebble sized); mode about 40 mm.; rare boulders; mainly subrounded; dip and rock-types as above.	8"	20'-20'8"
Gravel: Similar to (A) above.	8"	20'8"-21'4"
Gravel: Similar to (B) above, but more poorly sorted.	3'	21'4"-24'4"
Gravel: Similar to (A) above.	1'	24'4"-25'4"
Sand: Brownish gray; 20% pebbles; trace of cobbles; moderately to well sorted; mostly medium to very coarse sand; cross-bedding; rock-types as above.	4'	25'4"-29'4"
Gravel: Similar to (B) above but poorly sorted.	5'	29'4"-34'4"
Gravel?:Covered.	9'	34'4"-43'4"

Section III. Kame deposits -- near Loder's Lime Ltd. north of Route 1A (51°04' 40" N. latitude; 115° 07' 20" W. longitude).

Soil: With pebbles and boulders.	6"	0"- 6"
Pebbly sand: Poorly sorted.	1'4"	6"- 1'10"
Gravel: Unconformable with above; gray; sandy; moderately sorted; 85% pebble-sized or larger; largest pebble 6" long; fragments generally well rounded; 15% sand; rock-types mainly limestone and dolomite; dip N52°E, $\pm$ 35°.	2'2"	1'10"- 4'

	Thickness	Depth
Pebbly sand: Poorly sorted.	1'4"	4'-5'4"
Gravel?: Covered.	6'+	5'4"-11'4"+

Section IV: Kame deposits -- Northeast of Bow River just west of Kananaskis Falls
(51° 05' 50" N. latitude; 115° 03' 50" W. longitude).

Soil:	3"	0"- 3"
Gravel: Gray sandy; moderately sorted; about 85% pebbles; mode 10-25 mm.; few boulders 1 1/2 feet long; subangular to well rounded fragments; rock-types mainly dolomite and limestone; fairly flat lying.		
Gravel: Unconformable with above; lt. gray; moderately sorted; 70% pebble sized or larger; mode 20-40 mm.; few boulders larger than 6"; fragments angular to subrounded; calcareous cement common; dip S80°E, 10-20%; rock-types as above.	2'6"	3"-2'9"
Gravel: Gray; sandy; moderate to well sorted; 85% to 95% pebbles; mode 15-25 mm.; subangular to rounded pebbles; calcareous cement; dip S80°E 10-20%; rock-types as above.	2'7"	2'9"-5'4"
Gravel: As above but mode about 15 mm.	1'7"	5'4"-6'11"
Gravel: Gray; poorly sorted; mainly boulders (up to 10"); mode 4"; angular to rounded; some pebbles and sand; dip and rock-type as above.	8"	6'11"-7'7"
(A) Sand: Some pebbles and granules; dip as above.	5"	7'7"- 8'
Gravel: Lt. gray; mainly pebbles; mode 50 mm.; remainder mainly sand and granules; dip and rock-types as above.	4"	8'-8'4"
Sand: As (A) above.	5"	8'4"-8'9"
Gravel: Lt. gray sandy; poorly to moderately sorted; 70% pebbles; mode 25 mm.; few cobbles up to 7"; dip and rock-types as above.	9"	8'9"-9'6"

	Thickness	Depth
Gravel: Lt. gray; sandy; well sorted; 85% pebbles up to 25mm.; mode 15 mm.; dip and rock-types as above.	8"	9'6"-10'2"
Gravel: Gray; sandy; moderately sorted; 85% pebbles; mode 25 mm.; some boulders up to 4" dip and rock-types as above.	1'3"	10'2"-11'5"
Gravel: Gray; 50% pebbles, 50% granules and smaller; moderate to well sorted; pebbles 4 mm. to 40 mm.; mode 15mm.; subangular to rounded; rock-types and dip as above.	2'6"	11'5"-13'11"
Gravel: Gray; sandy; moderately sorted; 85% to 90% pebbles; mode 7-25 mm.; few cobbles up to 5"; subangular to rounded; dip and rock-types as above.	5'6"	13'11"-19'5"
Gravel: Gray; sandy; poorly sorted; 50% boulders; mode 6"; boulders up to 1 foot, subangular to well rounded; 20% pebbles, 25 mm. mode; subangular to rounded; dip and rock-types as above.	1'	19'5"-20'5"
Gravel: Covered in part.	3'8"+	20'5"-24'1"+

Section V. Non-ice-contact outwash -- northwest side of Carrot Creek about 6 miles southeast of Banff townsite (51° 09' 10" N. latitude; 115° 25' 40" W. longitude).

Soil:	1'	0'-1'
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(A) Till (mudflow?): Lt. olive gray; firm; unsorted; 90% calcareous, less than 4 mm.; 10% pebble sized or greater; mode 15-25 mm.; subangular to well rounded fragments, mainly subrounded; less than 1% boulders up to 1 1/2 feet; poorly defined orientation of pebbles; rock-types consist mainly of limestone, dolomite, quartzitic sandstone, quartzite and chert; fairly flat lying.	5'	1'-6'
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Gravel and Sand: Alternating bands (1-3 ") of sand and gravel; gravel mainly pebbles poorly to moderately sorted, mode 15-25 mm.; subangular to subrounded; sand fine to coarse with scattered pebbles; some clay lenses (3 mm. $\pm$).	1'6"	6'-7'6"
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	Thickness	Depth
(B) Gravel: Gray-brown; poorly sorted; 60-70% pebble-sized or larger; mode 50-75mm.; subangular to subrounded poorly bedded; rock-types as above.	10'	7'6"-17'6"
Sand: Pebbles common; medium brown; fine-grained.	4'	17'6"-21'6"
Till(mudflow?): As (A) above, but 85% less than 4mm.; mode of large-size fraction about 40mm.; a few 1/2 - 1 inch interbedded sand lenses.	9'	21'6"-30'6"
Gravel: As (B) above but mode of large-sized fraction 25-40 mm.	2'6"	30'6"-33'
Gravel: Gray-brown; some sand; very poorly sorted; 65% pebble sized or larger; mode about 4" , less than 1% boulders up to 1 1/2 feet in diameter; subangular; rare band (1-2 inches) of pebbles with no fine material, rock-types as above.	22'	33'-55'
Gravel?: Covered.	4'	55'-59'

Section VI. Non-ice-contact outwash -- northwest side of Route 1A about 3 miles southeast of Canmore (51° 04' 10" N. latitude; 115° 17' 50" W. longitude).

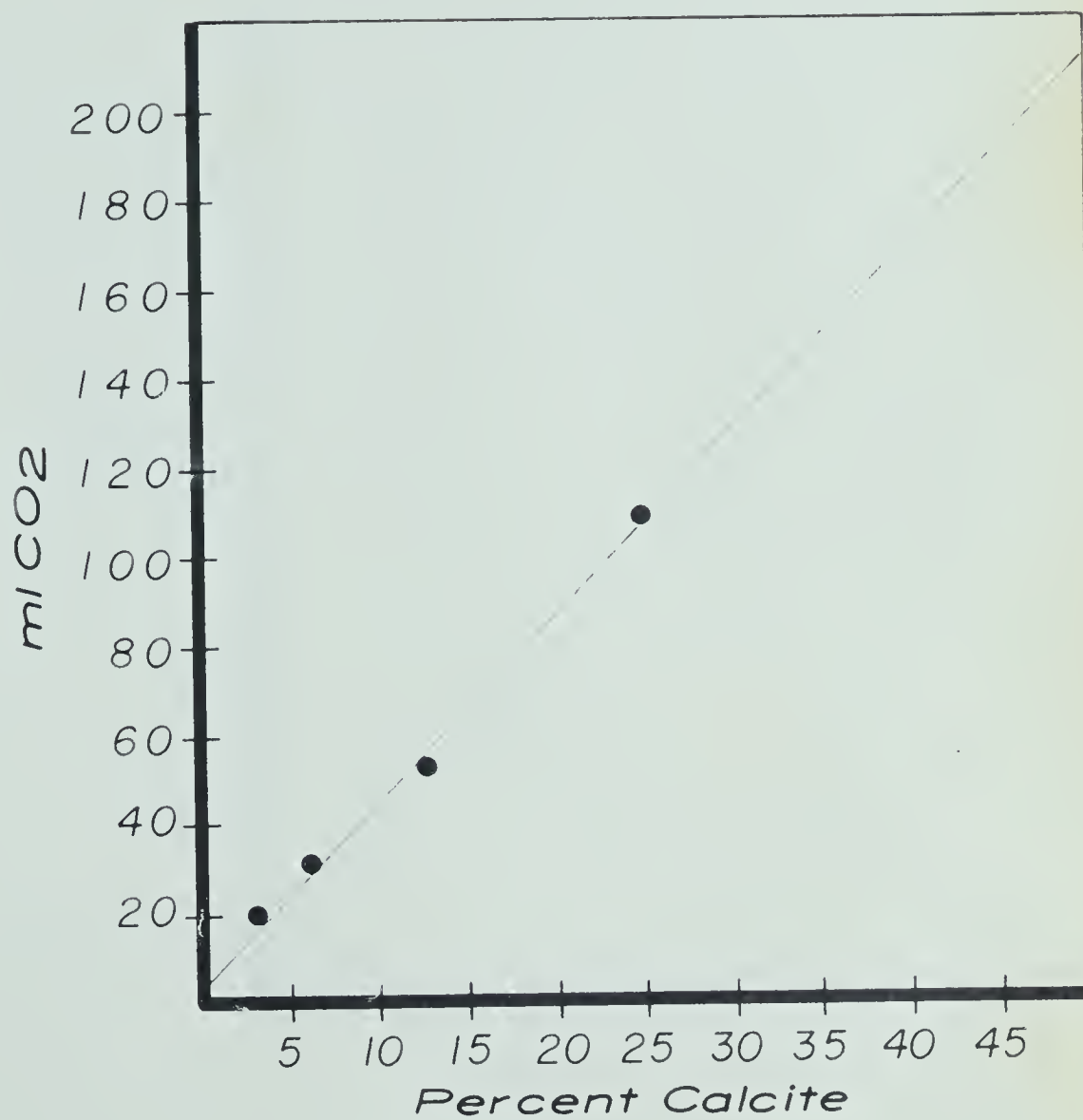
Gravels: Inaccessible for description	51'	0'-51'
(A) Gravel: Gray-brown; sandy, moderately to well sorted; 65-75% pebbles, mode 15-25 mm.; subangular to well rounded; rock-types mainly limestone, dolomite, quartzitic sandstone, quartzite and chert; fairly flat lying.	2'	51'-53'
Gravel: Mainly well sorted granule-sized material, dip and rock-types as above.	6"	53'-53'6"
Gravel: As (A) above.	3'	53'6"-56'6"
Gravel: Gray-brown; poorly sorted; 80% pebble-sized or larger; mode about 50 mm.; up to 6" cobbles; subangular to well rounded; dip and rock-types as above.	2'6"	56'6"-59'
Sand: Gray-brown 45% pebbles, mode 25-50mm.; subangular to well rounded; dip and rock-types as above.	6"	59'-59'6"

	Thickness	Depth
Gravel: As (A) above.	2'8"	59'6"-62'2"
Gravel: Gray-brown; 75% pebble-sized or larger; mode less than 7 mm.; subangular to well rounded pebbles; cross-bedded; dip 15° S70°E; rock-types as above.	2'5"	62'2"-64'7"
Gravel: As (A) above.	17'9"	64'7"-82'4"
Sand: Lens; cross-bedding.	1'7"	82'4"-83'11"
Gravel: As (A) above.	5'	83'11"-88'11"
Gravel?:Covered.	10'	88'11"-98'11"

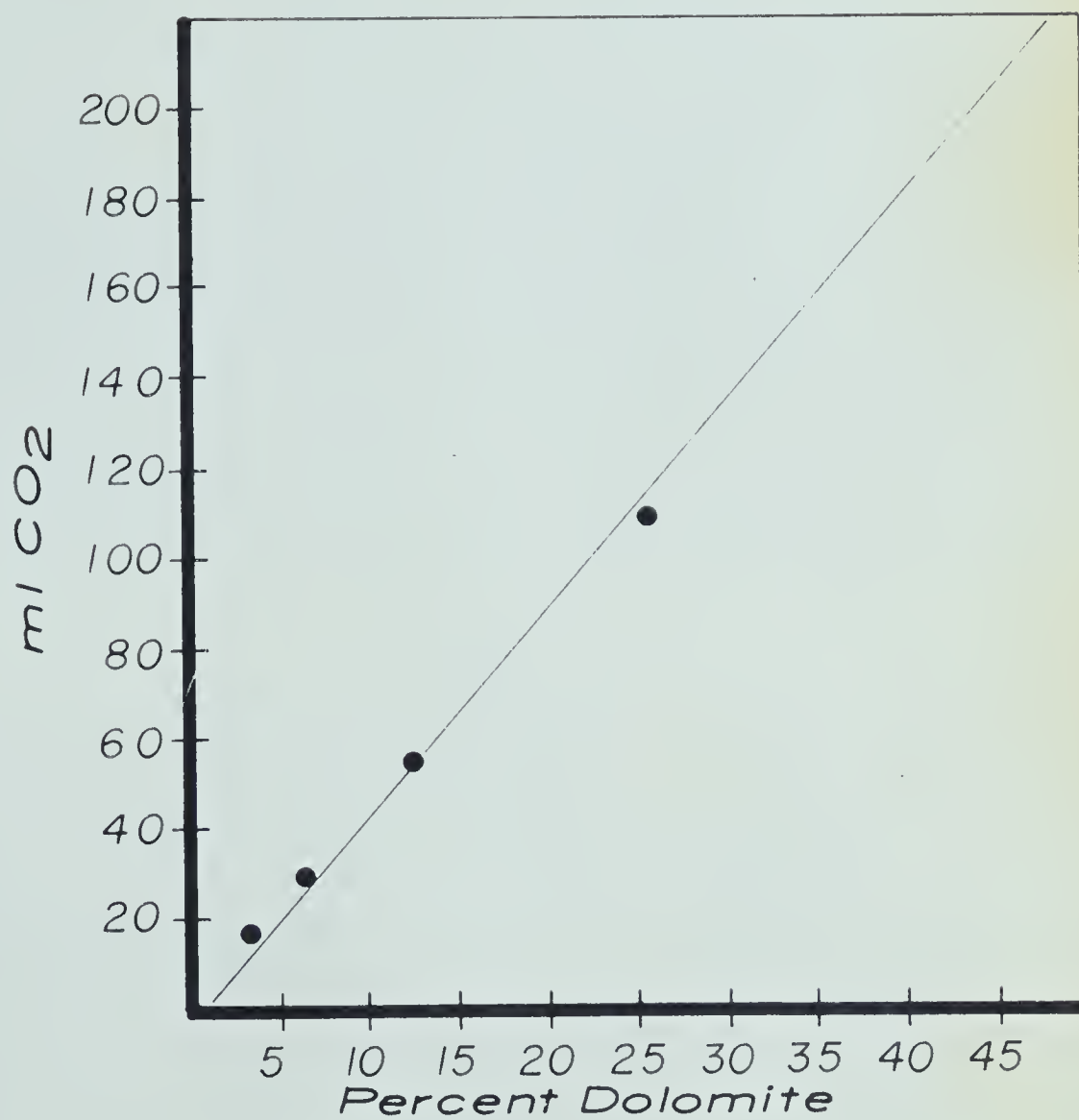
APPENDIX B

Results of tests using known amounts of pure calcite and dolomite (U.S. Bureau of Standards B.S. #88) for checking reliability of Chittick apparatus. Determinations plotted on standard graph (Dreimanis, 1962, p. 524) (Graphs A and B). All results were corrected for temperature and barometric pressure.

Sample No.	Sample Wt.	Vol. Reading (ml)	Temp. in System (°C)	Barometric Pressure (inches)	Vol. Correction for T & P (ml)	% Calcite or Dolomite from Std. Graph	Known % of Calcite or Dolomite Corrected to 1.700 gm. Sample
Calcite std.	.4250	112.4	22.0	27.85	108.9	25.2	25.0
Calcite std.	.2125	55.4	23.0	27.85	53.4	11.5	12.5
Calcite std.	.1063	33.3	22.5	27.85	32.2	6.5	6.3
Calcite std.	.0532	21.6	22.5	27.85	20.9	3.7	3.1
Dolomite std.	.4250	112.6	23.0	27.94	108.9	24.2	25.0
Dolomite std.	.2125	56.7	23.0	27.94	54.8	12.5	12.5
Dolomite std.	.1063	29.4	23.0	27.94	28.4	6.7	6.3
Dolomite std.	.0532	19.0	22.5	27.94	18.4	4.5	3.1



Graph A. Gas volume determination for percentage of known amounts of calcite to test the Chittick apparatus. Plotted on standard graph. (After Dreimanis 1962).



Graph B. Gas volume determination for percentage of known amounts of dolomite to test the Chittick apparatus. Plotted on standard graph. (After Dreimanis 1962).

A. Mt. Eisenhower. Bench-and-slope topography is prominent as a result of differential erosion of alternating lithologies of a broad, shallow syncline whose axis strikes northwestward. View toward north. (Photo by D. Harmon).

B. Valley of the Ten Peaks. Bench-and-slope topography is present, but not as prominent as in Plate 1A. View toward southwest. (Photo by W. J. L. Gibbons).

Plate I



A



B

A. Ice-cored moraine of Wenkchemna Glacier viewed toward the southwest showing thin (2 to 4 feet) coat of ablation moraine over clear ice.

B. Till A exposed in canyon about 3 1/2 miles north-northwest of Canmore. View toward northwest (51° 08' 00" N. latitude; 115° 23' 20" W. longitude).



A



B

Stereopair of two or possibly three successive cirques 2 miles southeast of Protection Mountain. ($51^{\circ} 23' 30''$ N. latitude; $116^{\circ} 00' 00''$ W. longitude). Alberta Government photographs.

Plate III



Low, parallel erosional ridges and shallow depressions in till at Corral Creek near Lake Louise (not in study area). Forest free zones exaggerate the sharpness of break between ridges. Alberta Government photographs.

Plate IV

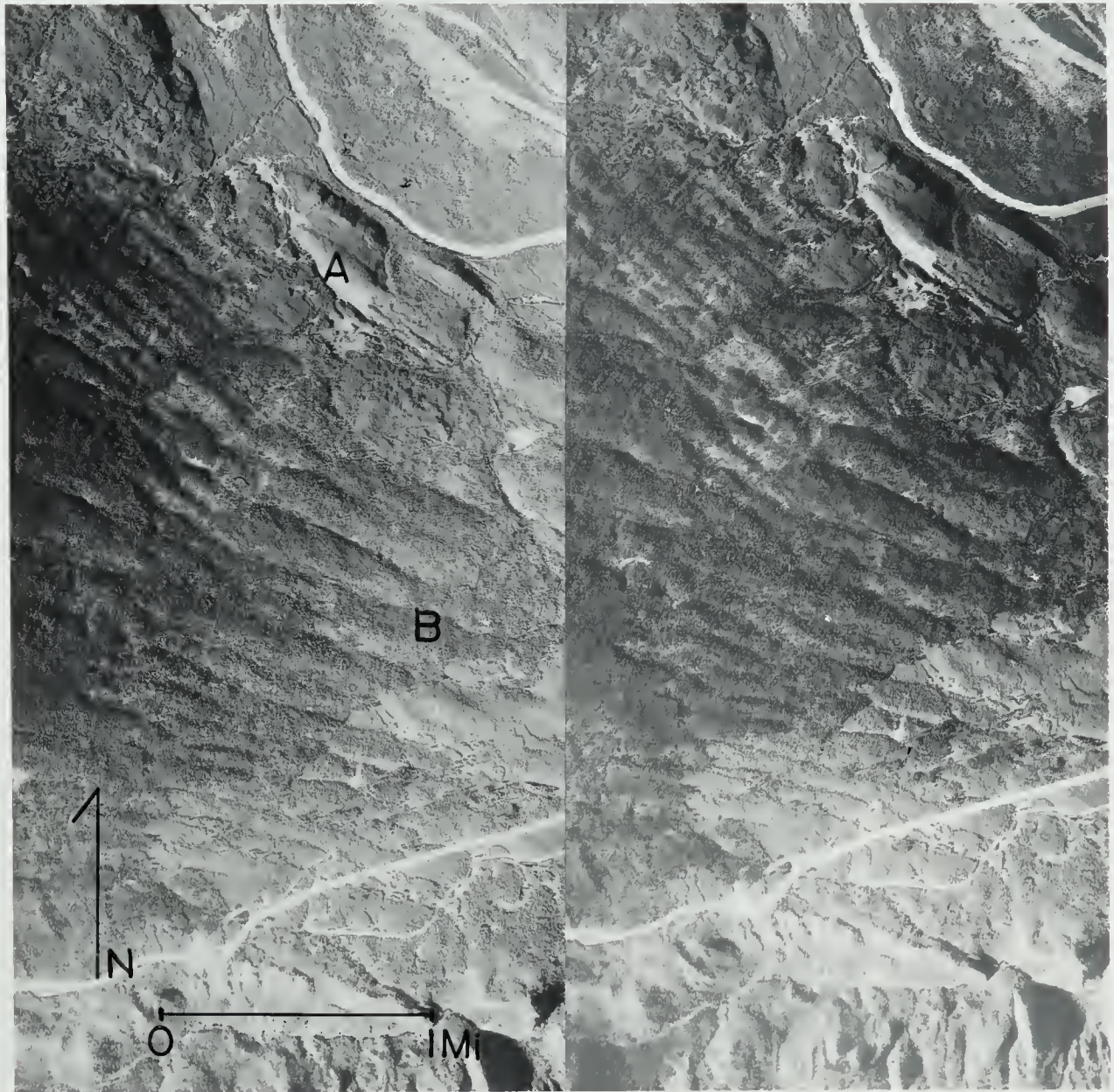


Stereopair of ice-contact fluvial complex near Eisenhower Junction. Route 93 in southern part of area and Bow River in northern part.

A. Erosional Ridges. B. Abandoned side glacial stream channels.

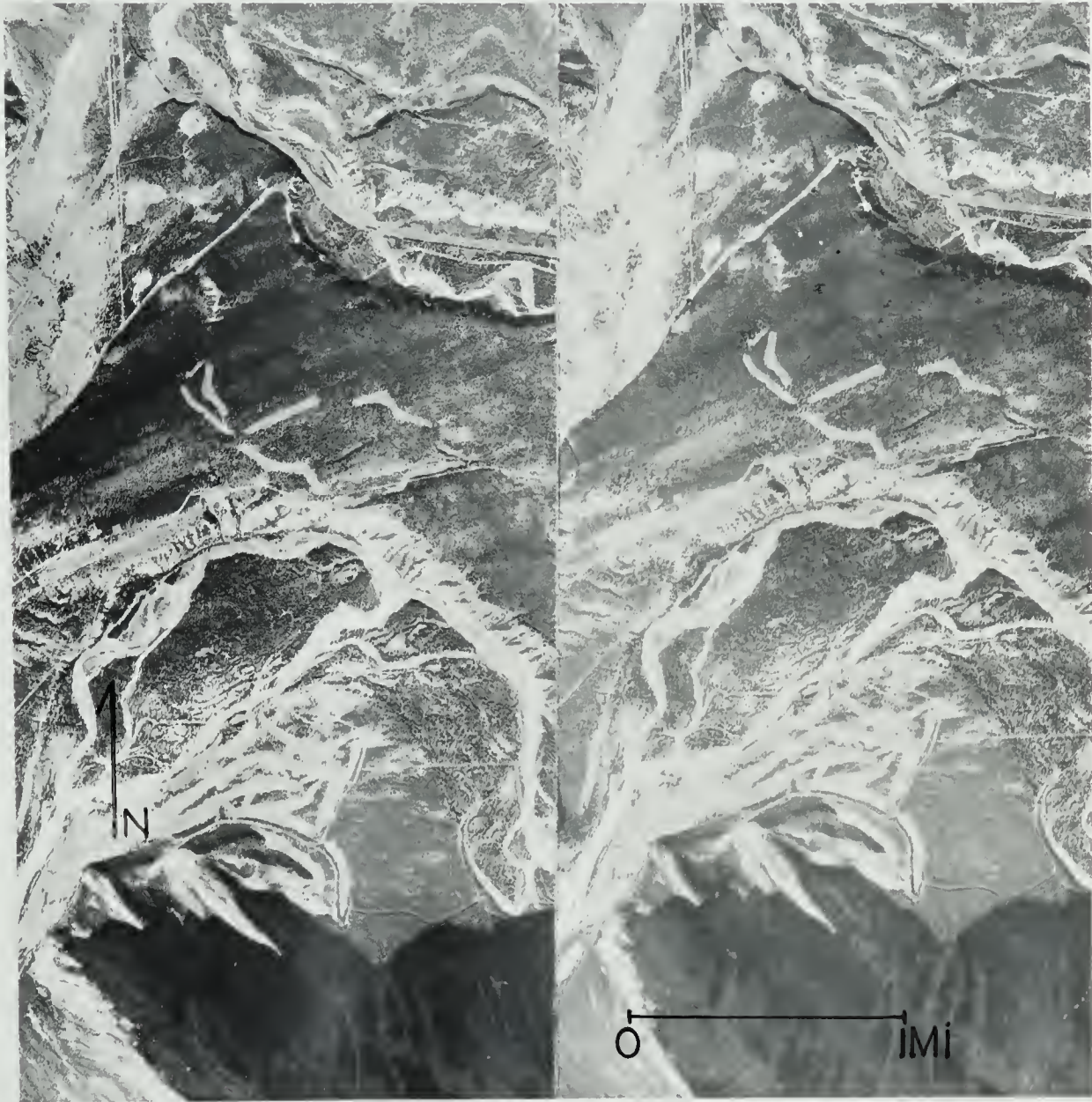
Alberta Government photographs.

Plate V



Stereopair of large scale erosional ridges and depressions in till beds on the north-east side of Tunnel Mountain near Banff townsite. Bow River near center of plate. Alberta Government photographs.

Plate VI



Kame moraine consisting principally of kame, eskers, and crevasse fillings? located between Kananaskis and Seebe. Bow River in northern part of area, Route 1 in southern part. Alberta Government photographs.

Plate VII



Powerhouse section -- Bow Valley Till overlying outwash gravels about 1/2 mile southwest of the Banff powerhouse on the southwest side of the Cascade River. View toward west-southwest. ($51^{\circ} 11' 40''$ N. latitude; $115^{\circ} 31' 00''$ W. longitude).

Plate VIII



- A. Eisenhower Junction Till (A) overlying ice-contact fluvial deposits (B). Dip of beds in the outwash is generally toward the southeast. View toward north. Note tape for scale. ($51^{\circ} 15' 45''$ N. latitude; $115^{\circ} 57' 00''$ W. longitude).
- B. Eisenhower Junction Till just north of Pipestone Creek near Lake Louise town-site (outside of mapped area). Note hammer for scale. ($51^{\circ} 25' 45''$ N. latitude; $116^{\circ} 10' 45''$ W. longitude).
- C. Thin (6 feet) glacio-fluvial deposits in the area of kame moraine. View toward south in shale pit near Kananaskis Falls. ($51^{\circ} 05' 30''$ N. latitude; $115^{\circ} 04' 00''$ W. longitude).

Plate IX



A



B

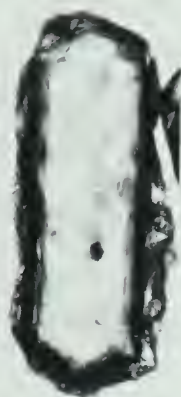


C

Some typical heavy minerals of till samples:

1. hypersthene
2. hypersthene
3. hypersthene
4. augite
5. zircon
6. zircon
7. zircon
8. zircon
9. tourmaline
10. tourmaline
11. tourmaline
12. tourmaline
13. chlorite
14. chlorite
15. clinozoisite

Plate X



1



2



3



4



5



6



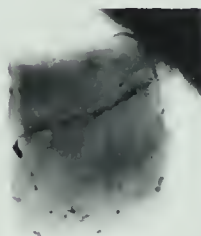
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8



9



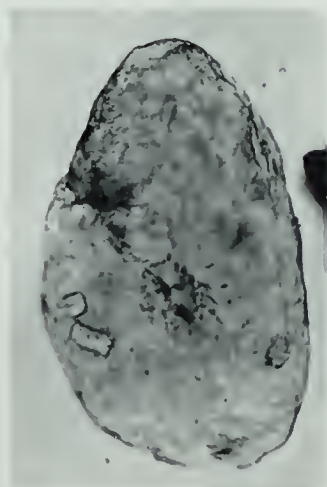
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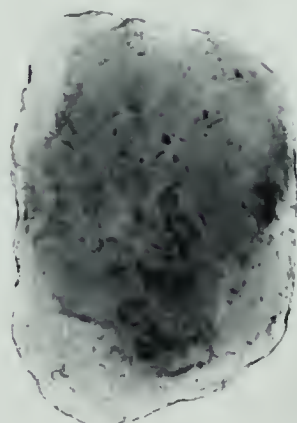
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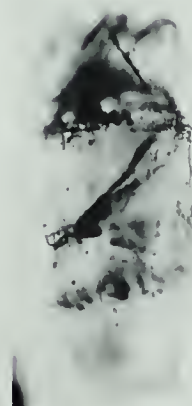
12



13



14



15

X62

Ice-contact fluvial deposits about 1 mile southwest of Eisenhower Junction. Regional dip and view toward the southeast. ($51^{\circ} 15' 40''$ N. latitude; $115^{\circ} 56' 40''$ W. longitude)

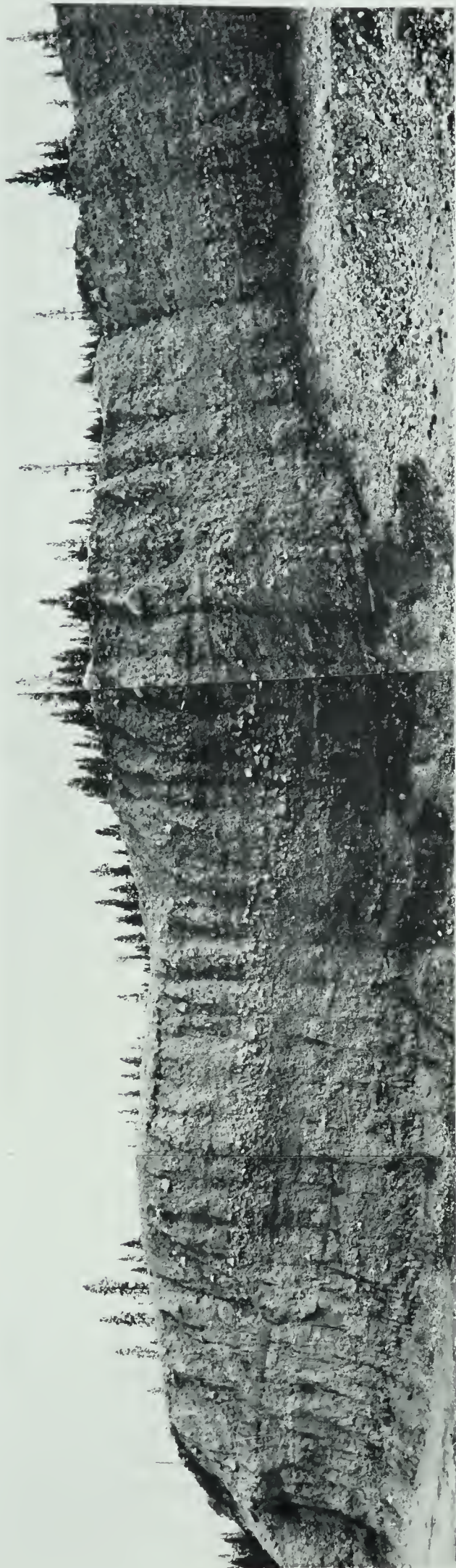


Plate XI

A. Kame deposits near Lodger's Lime Ltd. north of Route 1A. View toward east. (51° 04' 40" N. latitude; 115° 07' 20" W. longitude).

B. Non-ice-contact outwash exposed along the northeast side of Route 1A about 3 miles southeast of Canmore. View toward north. (51° 04' 10" N. latitude; 115° 17' 50" W. longitude).

Plate XII



A



B

Non-ice-contact outwash exposed along the northwest side of Carrot Creek about 6 miles southeast of Banff townsite. View toward northwest. ($51^{\circ} 09' 10''$ N. latitude; $115^{\circ} 24' 40''$ W. longitude).



Plate XIII

A. Non-ice-contact outwash exposed along the northeast side of Route 1A about 3 miles southeast of Canmore. Note cross-bedding and hammer for scale. View toward north. ($51^{\circ} 04' 10''$ N. latitude; $115^{\circ} 17' 50''$ W. longitude).

B. Lacustrine sediments on the north side of Lac des Arcs. Note shovel for scale. View toward north. ($51^{\circ} 03' 20''$ N. latitude; $115^{\circ} 10' 00''$ W. longitude).

Plate XIV



A



B

- A. Glacio-lacustrine deposits underlying aeolian sand near Banff townsite. Note volcanic ash layer. View toward north. ($51^{\circ} 12' 00''$ N. latitude; $115^{\circ} 31' 40''$ W. longitude).
- B. Face of old waterfall uncovered during dam construction near outlet of the Cascade River from Lake Minnewanka. View toward west. ($51^{\circ} 14' 30''$ N. latitude; $115^{\circ} 29' 40''$ W. longitude). Calgary Power Co. Ltd. photograph.



A



B

Oblique airphotograph of the eastern end of Lake Minnewanka to Devil's Gap.
View toward northeast. Dominion Government photograph.

Plate XVI



EXPLANATION

LITHOLOGY

PLEISTOCENE AND RECENT

NON-GLACIAL

26 FLOODPLAIN ALLUVIAL DEPOSITS : Gravel, minor Sand, Silt, and Clay

25 ALLUVIAL DEPOSITS, INCLUDING FANS : Gravel, minor Sand, Silt, and Clay

24 LANDSLIDE DEPOSITS : Rubble

23 LANDSLIDE DEPOSITS : Rubble, in part slung blocks of bedrock

22 TALUS DEPOSITS : Rubble

21 COLLUVIAL DEPOSITS (EXCLUDING TALUS) : Bedrock, Rubble, some Alluvium

20 POND AND ORGANIC DEPOSITS : Mostly Silt and Clay

19 ROCK GLACIERS

AEOLIAN

18 SAND DEPOSITS : In part dunes, buried soils common, some waterlain?

17 LOESS DEPOSITS : Fine Sand and Silt, minor Clay, yellowish Ash Layer

GLACIO-LACUSTRINE

16 LACUSTRINE DEPOSITS : Sand, Silt, and Clay, overlain by wind-blown Sand

15 LACUSTRINE DEPOSITS : Sand, Silt, and Clay; in part overlain by present day Bow River overbank by wind-blown Sand

GLACIO-FLUVIAL

14 NON-ICE CONTACT FLU. Gravel, Sand, minor Silt and Clay, some Till, occasionally overlain by till deposits (outwash, recessional moraines). Gravel, minor Sand, Silt, and Clay, some Till, occasionally overlain by patches of loess, washed gravel, and till.

13 ICE CONTACT FLUVIAL DEPOSITS (OUTWASH, RESSONAL MORAINES) : Gravel, minor Sand, Silt, and Clay, some Till, occasionally overlain by patches of loess, washed gravel, and till.

12 KANE MORAINIC DEPOSITS (OUTWASH) : Gravel, minor Sand, Silt, and Clay, some Cretaceous fillings?

11 ICE CONTACT FLUVIAL DEPOSITS (OUTWASH) : Gravel, minor Sand, Silt, and Clay

10 ICE-CONTACT FLUVIAL COMPLEX DEPOSITS (TERMINAL MORAINES) : Till and Gravel, minor Sand, Silt, and Clay

9 MELTWATER CHANNEL DEPOSITS : Gravel, Sand, minor Silt, and Clay

GLACIAL

8 GROUND MORAINIC DEPOSITS : Till, undisturbed, lenses of Gravel, Sand, and Silt, occasionally overlain by patches of loess, washed gravel, lacustrine deposits, and wind-blown Sand.

7 GROUND AND LATERAL MORAINIC DEPOSITS : Till, slightly modified by slope wash and marked by colluvium; Gravel, lacustrine deposits, and wind-blown Sand, bedrock exposed in part

6 GROUND AND LATERAL MORAINIC DEPOSITS : Till, greatly modified by slope wash and marked by colluvium; bedrock exposed in part

5 ICE-CORED MORAINIC : Mostly 2-4 foot layer of Abieson Machine over step-like ice.

4 DRUMLIN : Gravel drift, bedrock covered?

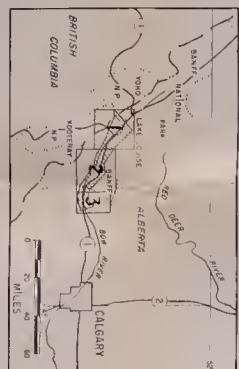
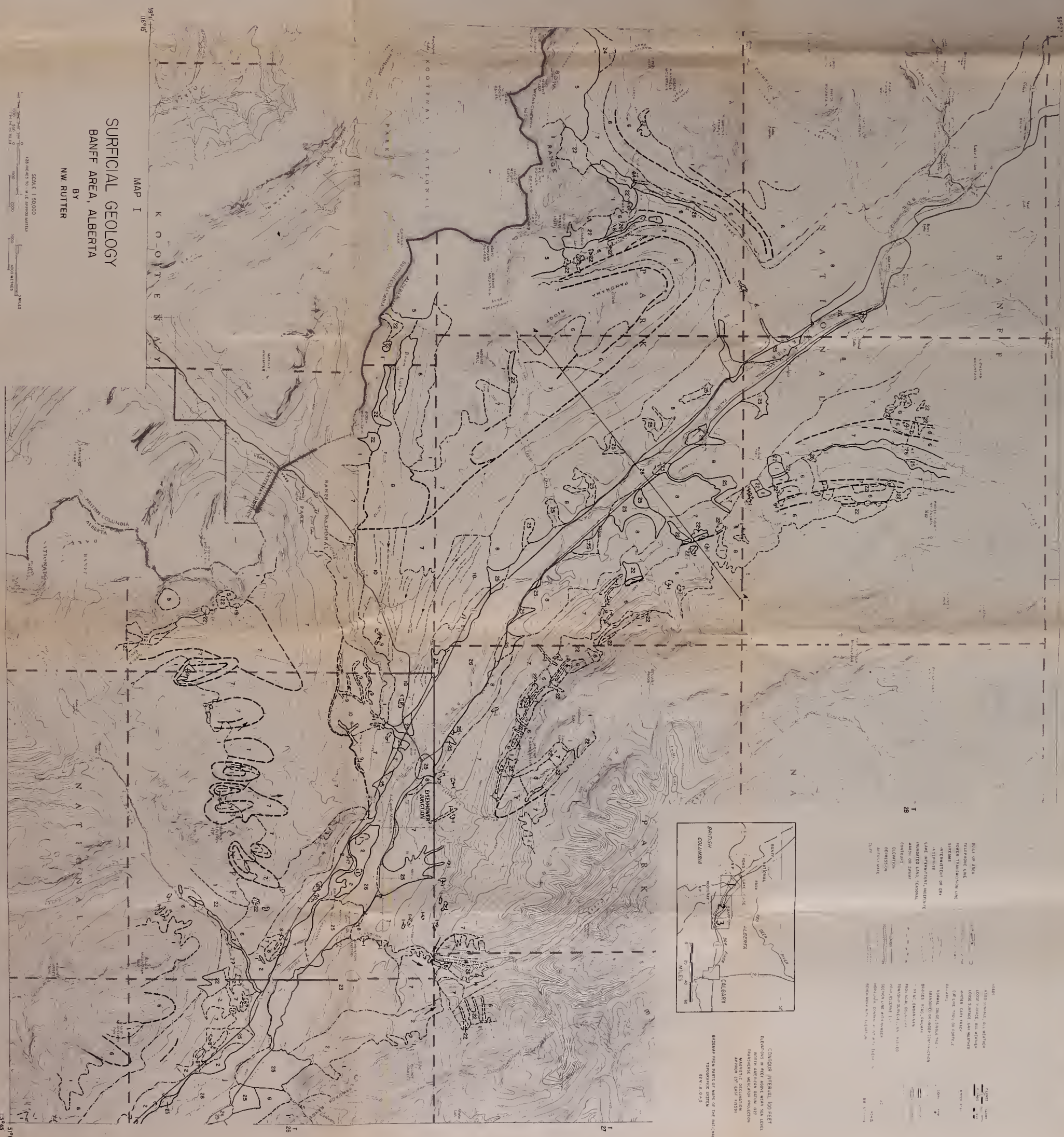
3 DRIFT COVERED BEDROCK KNOLLS

2 UNDIFFERENTIATED SURFICIAL DEPOSITS : Bedrock exposed in part

1 BEDROCK : Some with glacial striations, patches of colluvium

SURFICIAL GEOLOGY BANFF AREA, ALBERTA

BY
NW RUTTER



NOTE:
1. ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL.
2. NORTH ARROW INDICATES TRUE NORTH.
3. DISTANCE FROM MAPS OF THE BANFF AREA.
4. SCALE 1:50,000.
5. MAP OF ALBERTA, CANADA.
6. BANFF AREA, ALBERTA, CANADA.
7. DISTANCE FROM MAPS OF THE BANFF AREA.
8. SCALE 1:50,000.
9. MAP OF ALBERTA, CANADA.
10. BANFF AREA, ALBERTA, CANADA.

SCALE 1:50,000
1 INCH = 1.25 KILOMETERS
1 KILOMETER = 0.62 MILES

EXPLANATION

LITHOLOGY

PLEISTOCENE AND RECENT

NON-GLACIAL

- 26 FLOODPLAIN ALLUVIAL DEPOSITS: Gravel, minor Sand, Silt, and Clay.
- 25 ALLUVIAL DEPOSITS, INCLUDING FANS: Gravel, minor Sand, Silt, and Clay.
- 24 LANDSLIDE DEPOSITS: Rubble.
- 23 LANDSLIDE DEPOSITS: Rubble, in part slump blocks of bedrock.
- 22 TALUS DEPOSITS: Rubble.
- 21 COLLUVIAL DEPOSITS (EXCLUDING TALUS): Bedrock Rubble, some Alluvium.
- 20 POND AND ORGANIC DEPOSITS: Mainly Silt and Clay.
- 19 ROCK GLACIERS.

AEOLIAN

- 18 SAND DEPOSITS: In part dunes, buried soils common; some waterlain?
- 17 LOESS DEPOSITS: Fine Sand and Silt, minor Clay; volcanic Ash Layer.

GLACIO-LACUSTRINE

- 16 LACUSTRINE DEPOSITS: Sand, Silt, and Clay; overlain by wind-blown Sand.
- 15 LACUSTRINE DEPOSITS: Sand, Silt, and Clay; in part reworked by present day Bow River; overlain by wind-blown Sand.

GLACIO-FLUVIAL

- 14 NON-ICE CONTACT FLU- Gravel, Sand, minor Silt and Clay; some Till; occasionally overlain by patches of Loess, washed Gravel, Lacustrine Deposits, wind-blown Sand, and Till.
- 13 ICE-CONTACT FLUVIAL DEPOSITS (OUTWASH, RECESSONAL MORAINES): Gravel, minor Sand, Silt, and Clay; some Till; occasionally overlain by patches of Loess, washed Gravel, and Till.
- 12 KAME MORAINE DEPOSITS (OUTWASH): Gravel, minor Sand, Silt, and Clay; some Crevasse Fillings?; framework of Non-ice Contact Outwash.
- 11 ICE-CONTACT FLUVIAL DEPOSITS (OUTWASH): Gravel, minor Sand, Silt, and Clay.
- 10 ICE-CONTACT FLUVIAL COMPLEX DEPOSITS (TERMINAL MORAINES): Till and Gravel, minor Sand, Silt, and Clay.
- 9 MELT-WATER CHANNEL DEPOSITS: Gravel, Sand, minor Silt, and Clay.

GLACIAL

- 8 GROUND MORAINIC DEPOSITS: Till, undisturbed; lenses of Gravel, Sand, and Silt; occasionally overlain by patches of Loess, washed Gravel, Lacustrine Deposits, and wind-blown Sand; occasionally bedrock exposed.
- 7 GROUND AND LATERAL MORAINIC DEPOSITS: Till, slightly modified by Slope Wash and masked by Colluvium; lenses of Gravel, Sand, and Silt; occasionally overlain by patches of Loess, washed Gravel, Lacustrine Deposits, and wind-blown Sand; bedrock exposed in part.
- 6 GROUND AND LATERAL MORAINIC DEPOSITS: Till, locally modified by Slope Wash and masked by Colluvium; bedrock exposed in part.
- 5 ICE-CORED MORAINIC: Mainly 2-4 foot layer of Ablation Moraine over stagnant ice.
- 4 DRUMLIN: Glacial Drift; bedrock cored?
- 3 DRIFT COVERED BEDROCK KNDS.
- 2 UNDIFFERENTIATED SURFICIAL DEPOSITS: Bedrock exposed in part.
- 1 BEDROCK: Some with glacial erratics, patches of Colluvium.

- DEFINITE CONTACT
- APPROXIMATE CONTACT
- ASSUMED CONTACT
- LIMIT OF ICE DURING A MAJOR ADVANCE
- QUESTIONABLE LIMIT OF ICE DURING A MAJOR ADVANCE
- TERRACES
- MELT-WATER CHANNELS USUALLY WITH ASSOCIATED SEDIMENTS, LOW GRADIENT
- MELT-WATER CHANNELS ASSOCIATED WITH ICE-CONTACT FLUVIAL COMPLEX
- MELT-WATER CHANNELS USUALLY ERODED INTO BEDROCK, STEEP GRADIENT
- LIMITS OF RESTRICTED BEDROCK OUTCROPS
- GRAVEL PIT



EXPLANATION

LITHOLOGY

PLEISTOCENE AND RECENT

NON-GLACIAL

- 26 FLOODPLAIN ALLUVIAL DEPOSITS: Gravel, minor Sand, Silt, and Clay.
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- 19 ROCK GLACIERS.

AEOLIAN

- 18 SAND DEPOSITS: In part Dunes, buried Soils common, some waterlain?
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GLACIO-LACUSTRINE

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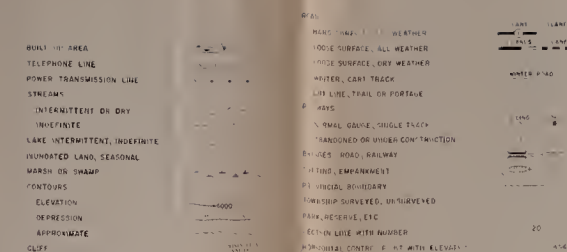
GLACIO-FLUVIAL

- 14 NON-ICE CONTACT FLU- Gravel, Sand, minor Silt and Clay, some Till; occasionally overlain by
VIAL DEPOSITS (DUT- patches of Loess, washed Gravel, Lacustrine Deposits, wind-blown Sand, and Till
WASH).
- 13 ICE-CONTACT FLUVIAL DEPOSITS (OUTWASH, RECESSONAL MORAINES): Gravel, minor Sand, Silt, and
Clay, some Till, occasionally overlain by patches of Loess, washed Gravel, and Till.
- 12 KAME MORaine DEPOSITS (DUTWASH): Gravel, minor Sand, Silt, and Clay; some Crevasse Fillings?;
framework of Non-Ice-Contact Outwash.
- 11 ICE-CONTACT FLUVIAL DEPOSITS (OUTWASH): Gravel, minor Sand, Silt, and Clay.
- 10 ICE-CONTACT FLUVIAL COMPLEX DEPOSITS (TERMINAL MORaine): Till and Gravel, minor Sand,
Silt, and Clay.
- 9 MELTwater CHANNEL DEPOSITS: Gravel, Sand, minor Silt, and Clay.

GLACIAL

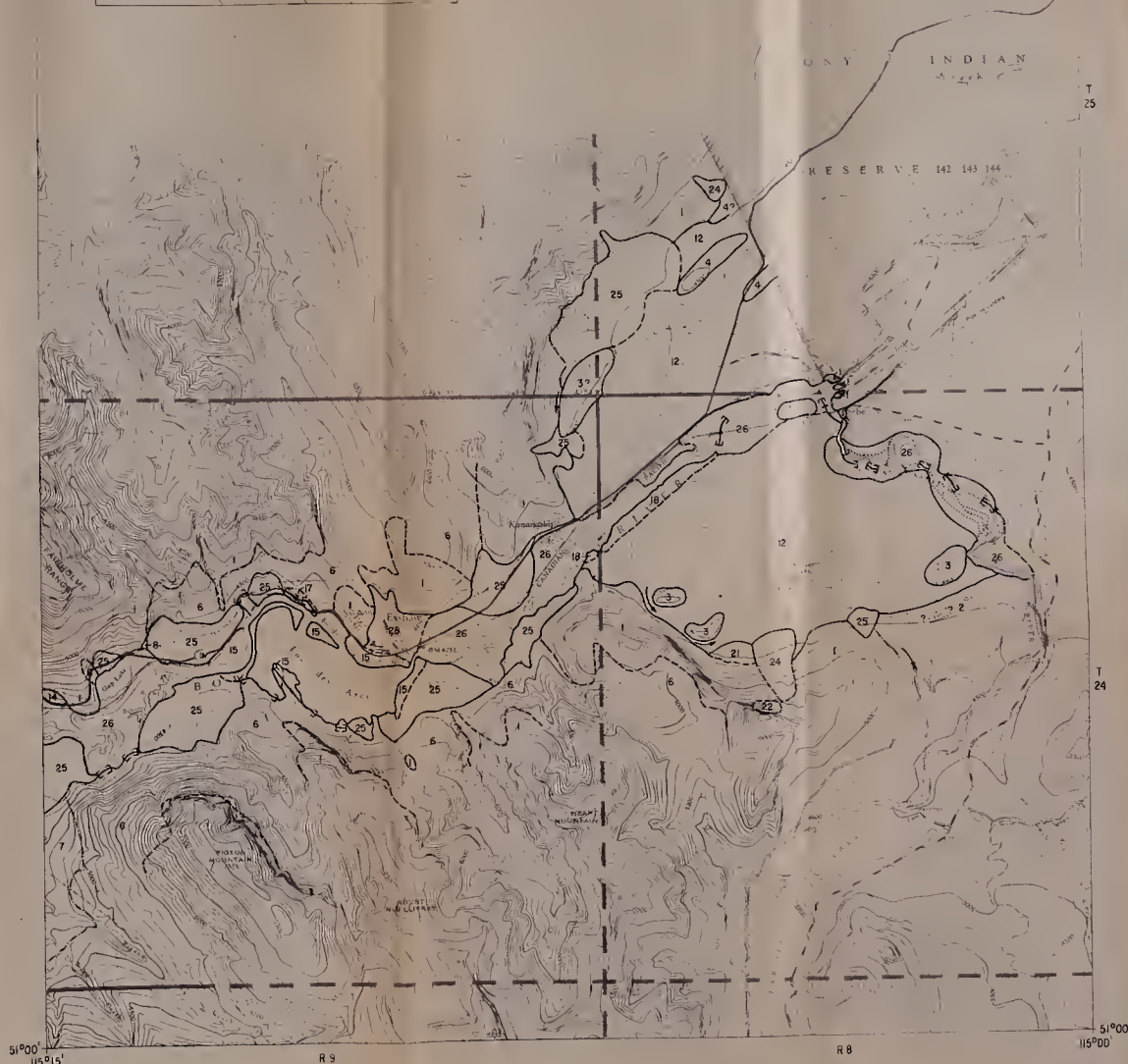
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patches of Loess, washed Gravel, Lacustrine Deposits, and wind-blown Sand,
occasionally Bedrock exposed.
- 7 GROUND AND LATERAL MORaine DEPOSITS: Till, slightly modified by Slope Wash and masked by Colluvium;
lenses of Gravel, Sand, and Silt; occasionally overlain by Patches of Loess, washed
Gravel, Lacustrine Deposits, and wind-blown Sand; Bedrock exposed in part.
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- DEFINITE CONTACT
- APPROXIMATE CONTACT
- ASSUMED CONTACT
- LIMIT OF ICE DURING A MAJOR ADVANCE
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- MELTwater CHANNELS ASSOCIATED WITH ICE-CONTACT FLUVIAL COMPLEX
- MELTwater CHANNELS USUALLY ERODED INTO BEDROCK, STEEP GRADIENT
- LIMITS OF RESTRICTED BEDROCK OUTCROPS
- GRAVEL PIT



INTOIR INTER-AL. 100 FEET
ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL
NORTH AMERICAN, 1927
TRANSVERSE MERIDIAN 115° 15' W.
MAGNETIC 115° 15' W.
AP. 115° 15' W.

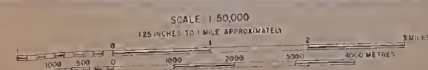
MAP FOR M. 115° 15' W.
115° 15' W.
115° 15' W.



MAP 3

SURFICIAL GEOLOGY BANFF AREA, ALBERTA

BY
NW RUTTER





MAP SYMBOLS

UNMAPPED (QUATERNARY)	1	Undifferentiated (principally Belly River Fm)	Mine or prospect
UPPER CRETACEOUS	2	Fernie and Kootenay (in part L. Cretaceous) Fms	Geological boundary
JURASSIC	3	Sulphur Mtn Fm	Indefinite geological boundary
TRIASSIC	4		Change in unit definition
MESOZOIC UNDIVIDED	5		Fault
PERMO-PENNSYLVANIAN	6	Sagey Lokes (in part Miss.) and Ishbel Gps	Inferred fault
MISSISSIPPIAN	7	Exshaw and Banff Fms, Rundle Gp.	Thrust fault
DEVONIAN	8	Fairholme Gp., U. Alsea and Follister Fms	Inferred thrust fault
ORDOVICIAN	9	Goodwin (McKay) (in part U. Cambrian) Fm, (equivalents in eastern part)	Axis of anticline
UPPER CAMBRIAN	10	Arctomys (in part M. Cambrian) Sullivan and Lyell Fms.	Inferred axis of anticline
MIDDLE CAMBRIAN	11	Cathedral, Stephen, Eldon, and Pico Fms.	Axis of overturned anticline
LOWER CAMBRIAN	12	Gog Group, Mt. Whyte (in part M. Cambrian) Fm.	Axis of syncline
CAMBRIAN UNDIVIDED	13	Includes some Precambrian in main range	Inferred axis of syncline
PALEOZOIC UNDIVIDED	14		Axis of overturned syncline
PRECAMBRIAN	15		Contour
IGNEOUS ROCKS (DEVONIAN)	16	Ice River Complex (Nephele "yenite" etc.)	River and stream
			Lake
			Railroad
			Main Road
			Secondary Road

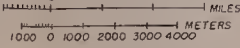
GENERALIZED GEOLOGIC AND TECTONIC COMPILED MAP

BANFF AREA, ALBERTA
1965

BY
N.W. RUTTER AND T.L. EVANS

Compiled from Maps of J.A. Allan, 1915;
E.L. Fitzgerald, 1963; G.G.L. Henderson, 1954;
C. Wright-Broughton, 1960

Contour interval 1000 feet
Drawn by Frank DIMITROV
Dept. of Geology
U of A





EXPLANATION

- NG NON-GLACIAL FLUVIAL, LACUSTRINE OR AELIAN DEPOSITS (EXCLUDING LOESS)
- C COLLUVIAL DEPOSITS (INCLUDING LANDSLIDES)
- IC ICE-CORED MORaine
- T TILL (SOME AREAS TILL MODIFIED OR DISCONTINUOUS)
- GF GLACIO-FLUVIAL DEPOSITS
- GL GLACIO-LACUSTRINE DEPOSITS (SOME IN PART AELIAN)
- L LOESS
- US UNDIFFERENTIATED SURFICIAL DEPOSITS
- BR BEDROCK (SOME WITH GLACIAL ERRATICS AND/OR COLLUVIUM)
- DEFINED CONTACT
- - - APPROXIMATE CONTACT
- - - ASSUMED CONTACT
- - - DEFINED LIMIT OF ICE DURING A CERTAIN EVENT
- C.Y. COAL YARD
- G.P. GRAVEL PIT

RELATIVE AGES OF SURFICIAL DEPOSITS

by
N.W. RUTTER

- NON-GLACIAL DEPOSITS
- 1 POST-BOW VALLEY ADVANCE TO RECENT
- GLACIAL DEPOSITS
- 2 19th CENTURY ADVANCE
- 3 POST-EISENHOWER JUNCTION-18th-19th CENTURY ADVANCE
- 4 EISENHOWER JUNCTION ADVANCE & RE-ADVANCE UNDIFFERENTIATED (SOME POST-BOW VALLEY, PRE-BOW VALLEY?)
- 5 BOW VALLEY ADVANCE (SOME PRE-BOW VALLEY?)
- 6 PRE-BOW VALLEY ADVANCE
- 7 BEDROCK (SOME WITH ERRATICS AND/OR COLLUVIUM) OR SURFICIAL DEPOSITS OF UNKNOWN AGE

- CONTACTS
- - - INFERRED LIMIT EISENHOWER JUNCTION ADVANCE
- - - INFERRED LIMIT BOW VALLEY ADVANCE
- - - INFERRED LIMIT BOW VALLEY RE-ADVANCE
- - - INFERRED BOUNDARY BETWEEN DEPOSITS OF A CERTAIN AGE

C.I. 1000 FT. (6000, 7000, 8000 FT ONLY)



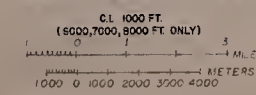
EXPLANATION

- | | |
|---|--|
| NG | NON-GLACIAL FLUVIAL, LACUSTRINE OR AELIAN DEPOSITS (EXCLUDING LDSS). |
| C | COLLUVIAL DEPOSITS (INCLUDING LANDSLIDES). |
| IC | ICE-CORED MORAINES |
| T | TILL (SOME AREAS TILL MODIFIED OR DISCONTINUOUS). |
| GF | GLACIO-FLUVIAL DEPOSITS. |
| GL | GLACIO-LACUSTRINE DEPOSITS (SOME IN PART AELIAN). |
| L | LDSS. |
| US | UNDIFFERENTIATED SURFICIAL DEPOSITS. |
| BR | BEDROCK (SOME WITH GLACIAL ERRATICS AND/OR COLLUVIUM). |
| — DEFINED CONTACT | |
| --- APPROXIMATE CONTACT | |
| - - - ASSUMED CONTACT | |
| - - - DEFINED LIMIT OF ICE DURING A CERTAIN EVENT | |
| C.Y. | CDAL YARD |
| G.P. | GRAVEL PIT |

SAMPLE LOCATION MAP

BANFF AREA, ALBERTA

• N-20 SAMPLE LOCATION



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